

EXECUTIVE SUMMARY

**INTEGRATED STUDY OF EXPOSURE AND BIOLOGICAL EFFECTS OF
IN-PLACE SEDIMENT POLLUTANTS IN THE UPPER CONNECTING CHANNELS:
INTERIM RESULTS**

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PREFACE

The following is a summary of the In-Place Sediment Pollutants (IPP) Project conducted on the Trenton Channel of the Detroit River as part of the Upper Great Lakes Connecting Channels Study (UGLCCS). This report is provided to meet reporting obligations to the Upper Great Lakes Connecting Channels Study for various tasks in Activities C (modeling), G (sediments), and H (biota). This executive summary is based on principal investigator interim reports; individual interim reports and data sets are appended for UGLCCS workgroup reference and use.

The In-Place Pollutants Study is being conducted under the direction of and with funding by the U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory-Duluth, Large Lakes Research Station. Completion of the final In-Place Pollutants Study report is scheduled for December, 1988. The intent of this submission is to provide as much information as possible to UGLCCS workgroups for the UGLCCS final report. Certainly, a considerable amount of interpretation, analysis, and synthesis remains to be completed. Many tasks have not been addressed to date, and this report discusses some tasks and analyses that will be conducted and finalized in the future. Therefore, the executive summary and interim reports have not been peer-reviewed and should be regarded as preliminary.

ABSTRACT

An interdisciplinary study of the Trenton Channel, Detroit River, was conducted between 1985 and 1988 to investigate the sources, transport, fate, and biological effects of toxic substances. The primary emphasis was to quantify sediment contamination and related toxicity, and to identify and predict the potential consequences associated with the physical dynamics of the ecosystem. This study provides direct evidence that sediments in the Trenton Channel are contaminated with a suite of heavy metals and organic contaminants. The sediment, sediment porewater, sediment elutriate, and lower water column samples induced toxic and/or mutagenic responses in a wide array of bioassay organisms. Sediment and/or associated samples inhibited metabolism, feeding rates, reproduction, and growth, and induced behavioral changes in and caused mortality among test organisms which encompassed the trophic spectrum from bacteria to fish. Tumors and pretumorous lesions (both external and internal) were observed in Detroit River fish populations indicating that a carcinogenic potential exists in this environment. Bioavailability of organic compounds was demonstrated by Detroit River diving ducks which contained relatively high concentrations of PCBs. Results indicate that the most adversely impacted region of the study area is a four-kilometer reach of the western, nearshore zone of the Trenton Channel from just north of the Monguagon Creek area southward to Elizabeth Park.

Results of resuspension, transport, and deposition studies indicate that this severely degraded zone has a great potential for impacts at adjacent and/or downstream localities. Conversely, considerable expanses of the study area exhibited relatively less contamination and little or no toxicity. A substantial amount of this study remains to be completed and will focus on relationships, processes, and mathematical modeling. Because Trenton Channel sediments possess a complex mixture of heavy metals and organic contaminants, additional statistical techniques must be applied to determine the most influential factors regarding toxicity. Although a correlative/multiple regression approach is instructive, multivariate techniques such as principal component analysis, factorial analysis, discriminate function analysis, and correspondence analysis may be the most informative. Probabilistic and mass balance modeling will standardize comparative dose-response functions derived from toxicity testing and will allow a comprehensive understanding of the sources, transport, fate, and effects of toxic substances in the Detroit River.

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This document is a preliminary draft. It has not been formally released by the U.S. Environmental Protection Agency and should not at this stage be construed to represent Agency policy. It is being circulated for comments on its technical merits and policy implications.

EXECUTIVE SUMMARY: INTEGRATED STUDY OF EXPOSURE AND BIOLOGICAL EFFECTS OF IN-PLACE POLLUTANTS IN THE UPPER CONNECTING CHANNELS

INTRODUCTION

OVERVIEW

Contaminated sediment is a global issue that is evident in all forms of freshwater systems and in the coastal and offshore marine environment as well. The Laurentian Great Lakes have not escaped the impacts of in-place pollutants. Contaminated sediment is one of the most serious and challenging problems confronting Great Lakes managers and scientists today. Thirty-eight of the 42 International Joint Commission Great Lakes Areas of Concern are classified as such because of contaminated sediments or have in-place pollutants as a factor in a suite of problems associated with these adversely impacted areas (Great Lakes Water Quality Board, 1985). Because of the extent and magnitude of the problem, in-place pollutants will continue to be a top research priority well into the next century, even if zero discharge is realized.

The Detroit River is an IJC Area of Concern and has a long history of conventional and non-conventional pollution. Substantial progress has been made in alleviating obvious and gross pollution problems through discharge allocations, permitting, and other mitigative actions. However, the problem

of in-place pollutants remains. The situation has arisen from almost a century of discharge and deposition of anthropogenic substances from industrial and municipal sources. The symptoms have become particularly acute during the past four decades with the advent of the chemical revolution.

Unchecked, the reservoir of anthropogenic substances contained within sediments will continue to have profound impacts on the St. Lawrence Great Lakes ecosystem: its beneficial use, water quality, biota, and man. Fundamental factors and questions such as: Are the sediments contaminated? How contaminated are they? Are the sediments toxic? How toxic are they? How much toxic material is present? Where are the most hazardous areas? What are the functional effects on the biota? Which trophic levels are potentially the most adversely impacted? What are the most influential contaminants? What are the potential consequences of sediment resuspension and transport? What is the appropriate assessment strategy? What are the goals of remediation? What are the necessary remedial measures? and How should contaminated sediment be properly handled? must be addressed. These questions must be viewed in a comprehensive manner along with factors such as cost, cost-effectiveness, benefit, regulation, and remediation. The concerns and problems facing this and the next generation are many times more subtle than in the past and are scientifically and economically more difficult to address. It is the charge, then, of researchers and managers to determine the sources, fate, transport, and biological effects of in-place pollutants. From results of these investigations, recommendations must ultimately be made to indicate where the most beneficial and cost-effective expenditure of regulatory and remedial dollars should be placed.

APPROACH AND OBJECTIVES

The In-Place Pollutants Study combines applied and fundamental research, and sets forth a comprehensive, multidisciplinary approach to the study, assessment, regulation, and remediation of contaminated sediments in large aquatic systems. The overall study end-product is applied, in that the study framework developed may be utilized in any ecosystem to recommend the optimal combination of remedial and regulatory strategies to management. The program framework is a research concept which through an evaluative process, will indicate which scientific components are necessary for an integrated approach for the assessment of contaminated sediments. However, individual study components and tasks require a considerable amount of research and development. The study of contaminated sediments is largely unstandardized and fundamental questions concerning appropriate test specimens, physical determinations, chemical measurements, sample processing techniques, and test endpoints are being explored and evaluated. During this project, new methodologies, equipment, and bioassays are being developed and tested. Also some conventional bioassay procedures used for water column and effluent testing are being adapted for sediment toxicity testing. Bioassays employed in this study represent the whole-effluent, toxicity-based, sediment approach.

The In-Place Pollutants Project is a multidisciplinary study which draws on four primary sciences: biology, chemistry, physics, and mathematics (statistics and modeling) as presented in Figure 1. Studies employing these sciences are integrated in space and time to provide data which aids the other sciences in determining causative factors, relationships, and allows

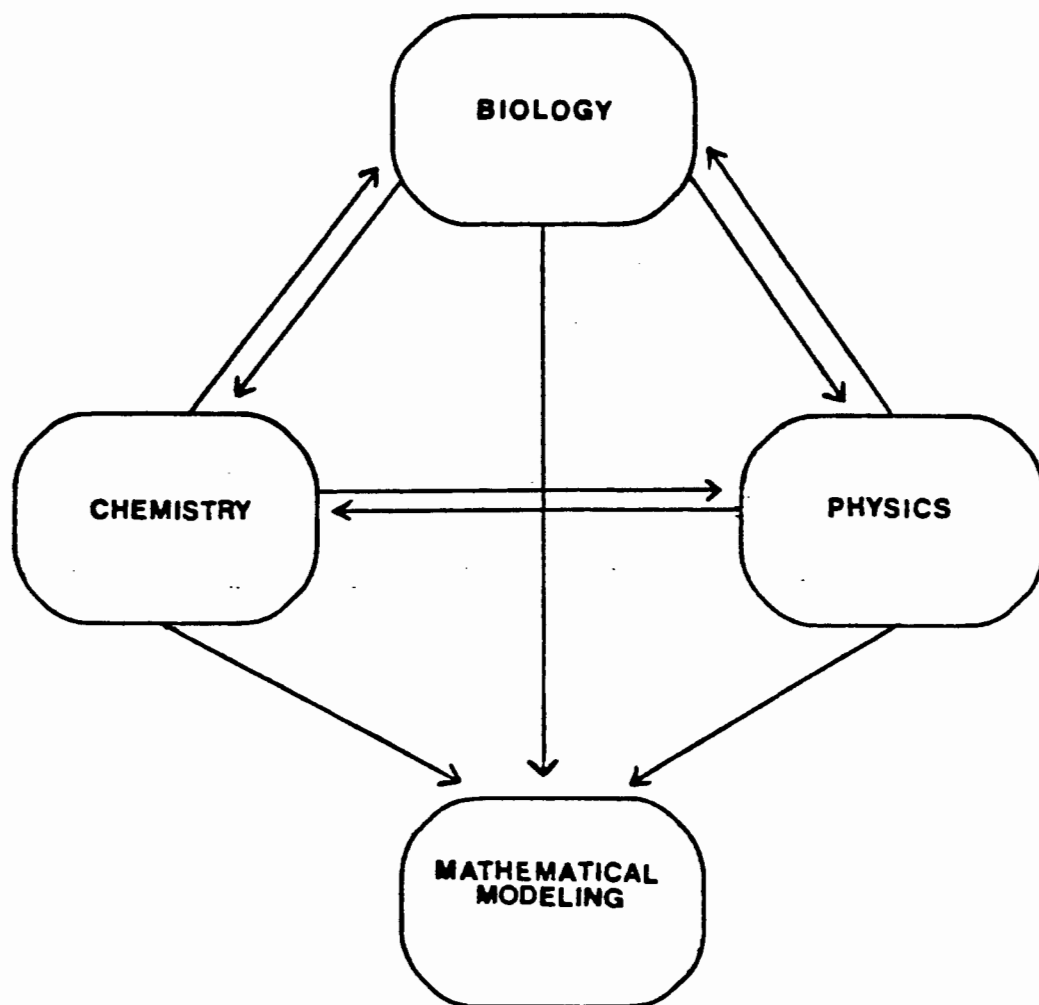


Figure 1. Relationship Between Scientific Disciplines Employed in the In-Place Pollutants Study.

comparative analyses through a compatible and complimentary data set. Typically, each discipline will produce autonomous end-products; however, chemistry and physics will be used for predicting the most likely causative factors of biological effects observed and in some instances, vice-versa. The strength of the approach is that all three sciences are synthesized through a statistical-based modeling framework. Results of the study are additionally synthesized through the Sediment Action Index which is a numerical ranking system used to identify and then prioritize the sites which are the most severely contaminated and toxic.

The In-Place Pollutant Project could be considered an autonomous, free-standing study but has been integrated with the Detroit River System Mass Balance (USEPA, LLRS, 1987a) and the Trenton Channel Microscale Mass Balance (USEPA, LLRS, 1987b) Projects. Synthesis of the three projects through mathematical modeling will enable inspection of the entire system and exposure probabilities which may be encountered. Objectives of the two mass balance studies and the In-Place Pollutants Project are numerous but are embodied in five primary management objectives (Table 1). In addition to the management objectives, each of the four disciplines have had general objectives identified (Table 2).

Numerous hypotheses are being examined during the course of the study. Of these, a primary, driving hypothesis is that:

- Given -
- 1) Sediment characteristics
 - 2) Sediment concentrations of pollutants
 - 3) Estimated probability distribution of suspended solids in the water column

Then one or more of the following biological effects:

- 1) Short-term acute effects

TABLE 1. MANAGEMENT OBJECTIVES

-
- Determine the sources, transport, fate, and biological effects of in-place pollutants.
 - Determine the status of ecosystem health.
 - Rank sites for potential hazard based on contaminant concentrations, biological toxicity, mutagenicity, carcinogenicity, and resuspension potential.
 - Recommend remedial action strategies commensurate with study conclusions.
 - Develop a guidance document for the integrative assessment of in-place pollutants in Great Lakes Areas of Concern.
-

TABLE 2. DISCIPLINE OBJECTIVES

MATHEMATICAL MODELING

- Determine the system mass balance of selected contaminants.
- Derive probabilistic relationships for biotic exposure to contaminants.
- Predict toxicological effects of in-place pollutants from suspended solids concentrations.

PHYSICS

- Physical characterization of Detroit River sediment types.
- Determine the hydrodynamic and shear-stress resuspension potential of various sediment types.

CHEMISTRY

- Spatially assess heavy metal and organic contaminant concentrations in Detroit River sediment.
- Determine sorption/desorption kinetics of various sediment types.

BIOLOGY

- Spatially assess sediment toxicity to several trophic levels of biota.
 - Assess the mutagenic, carcinogenic, and bioaccumulative potential of contaminants in sediment.
 - Determine the extent of tumor incidence in fish populations.
-

- 2) Long-term chronic effects on water column organisms
- 3) Direct effects on sediment dwellers and bottom feeders can be predicted directly from resuspension of in-place pollutants or indirectly from environmental factors affecting exposure of pollutants or classes of pollutants.

Two approaches can be taken to address this hypothesis (Figure 2). The first and primary approach is to determine whether sediments from selected sites in the study elicit toxic responses from test organisms in bioassays. In general, the end-points in each bioassay would indicate whether the site was toxic or not, the severity of toxicity, and allow an areal assessment of study area toxicity. The second approach is process oriented to aid in understanding the toxic responses observed and is designed to determine the most-likely causative factors and processes which are associated with toxicity. The In-Place Pollutants Study simultaneously applies both approaches for a more comprehensive study of sediment toxicity. Sediment bioassays are free-standing end-points and are the basis of the primary approach but are also required to apply the process-oriented methodology. Results of the bioassay approach is anticipated to produce direct correlations between suspended solids concentrations and toxicity (Figure 3). A predictive capability will also be obtained. In a probabilistic scenario, a series of relationships between solids concentrations, chemical concentrations, and toxicity will serve as end-points (Figure 4). These relationships will be expressed in terms of probabilistic modeling and can be converted to toxic units.

A wide array of primary study components have been identified to accomplish the objectives of the In-Place Pollutants Project (Table 3). Individual components are associated with the four scientific disciplines and

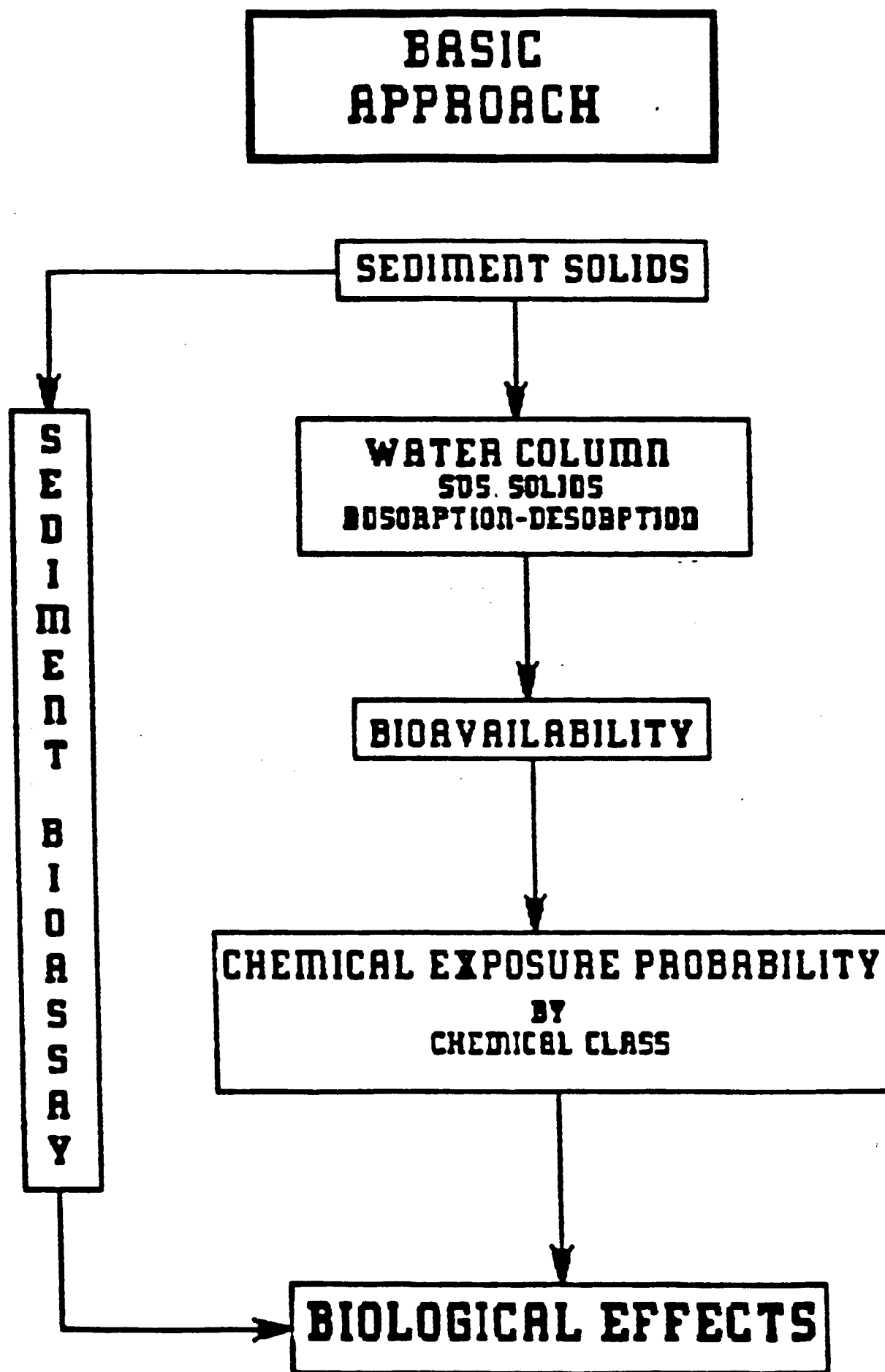


Figure 2. Basic, Dual-Pronged Approach Applied in the In-Place Pollutants Study.

UPPER CONNECTING CHANNELS STUDY
BIOLOGICAL EFFECTS OF INPLACE POLLUTANTS

DIRECT CORRELATION

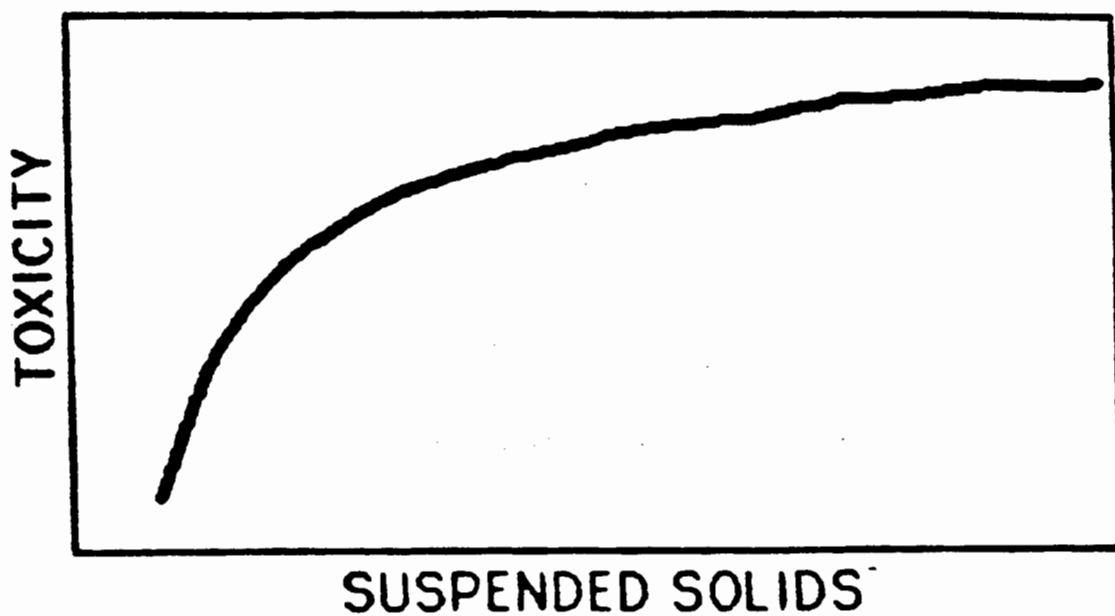


Figure 3. Relationship Between Biotic Toxicity and Suspended Solids.

UPPER CONNECTING CHANNELS STUDY
BIOLOGICAL EFFECTS OF INPLACE POLLUTANTS

CORRELATIONS AND PREDICTIONS EXPECTED

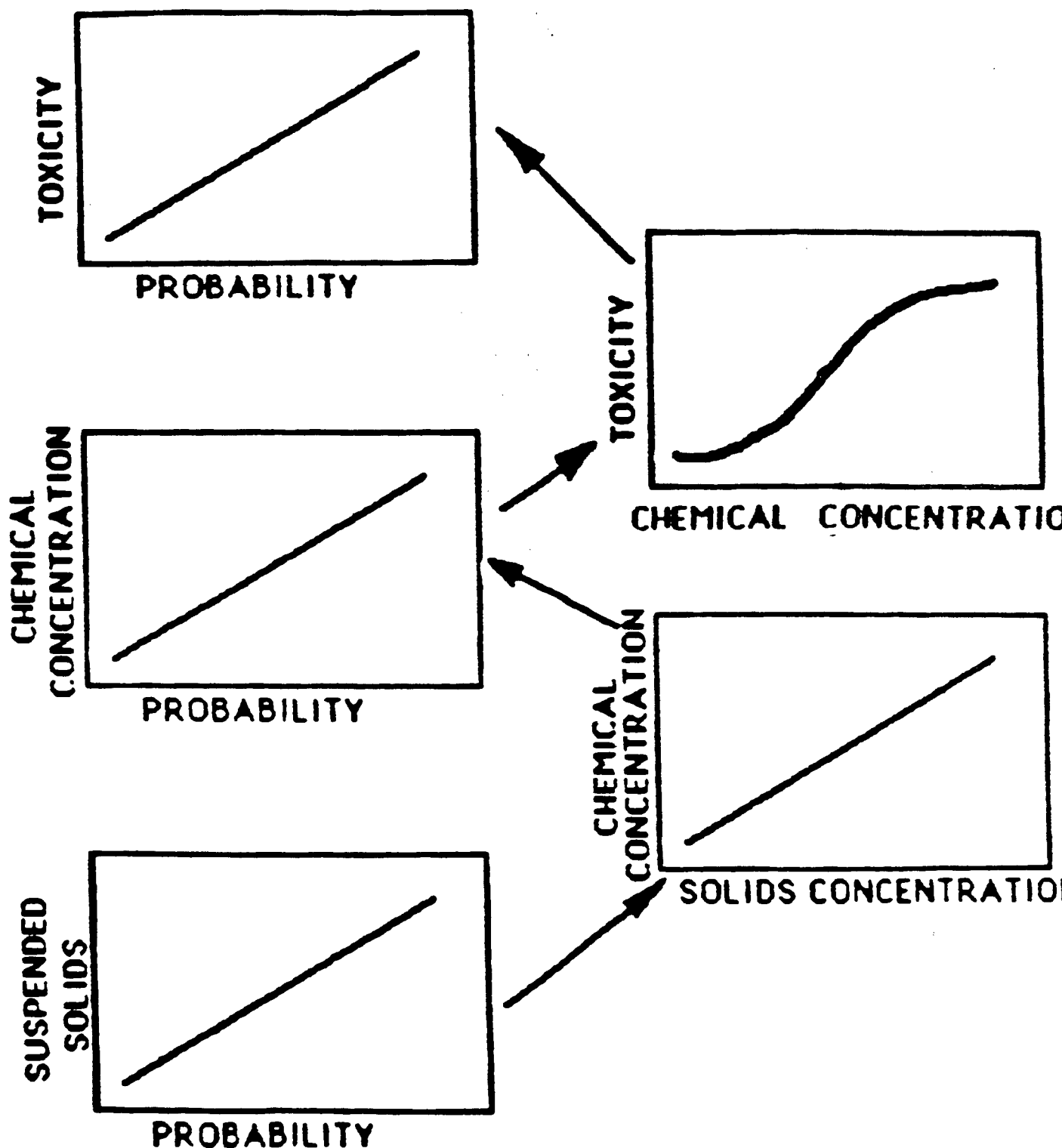


Figure 4. Probabilistic Relationships Between Solids and Chemical Concentrations and Toxicity.

TABLE 3. STUDY COMPONENTS

-
1. Mass Balance: Detroit River System and Trenton Channel Microscale.
 2. Loadings: High Frequency Bridge Sampling.
 3. Heavy Metal Concentrations: Sediment, Sediment Porewater, and Water.
 4. Organic Contaminant Concentrations: Sediment.
 5. Novel Organic Contaminants: Sediment, Fish.
 6. Sediment Characterization.
 7. Resuspension Probability.
 8. Sediment Resuspension, Transport, Deposition Potential.
 9. Sorption/Desorption Kinetics.
 10. Sediment Toxicity Bioassays.
 11. Lower Water Column Toxicity Bioassays.
 12. Bioavailability of Toxics.
 13. Sediment Mutagenicity and Carcinogenicity Potential.
 14. Yellow Perch Larvae Feeding Inhibition.
 15. Probabilistic Modeling.
 16. Vertical Contamination and Toxicity.
 17. Fish Tumor Surveillance.
 18. Causative Factors in Fish Tumor Incidence.
-

fulfill the needs and objectives of the discipline, associated disciplines, and of the project. The study components include mass balance and probabilistic modeling; sediment characterization; resuspension and transport potential; chemical concentrations in sediment, sediment porewater, water, and biota; and toxic, mutagenic, and carcinogenic responses from bioassays.

Each study component has an additional level or set of tasks to be accomplished. For example, if study components 10-14 are examined in detail, 15 individual tasks (bioassays) are identified (Table 4). The bioassays use a number of test specimens which span the trophic spectrum from bacteria to fish. Also a number of functional, test endpoints/processes are being investigated, i.e., metabolism, growth, reproduction, feeding, behavior, bioaccumulation, mutagenicity, and carcinogenicity.

ORGANIZATION AND STRUCTURE

A multidisciplinary research team of governmental and academic scientists and engineers have been assembled to accomplish the study goals. Each group has been assigned study components and tasks which fulfill requirements of the interdisciplinary study objectives. Principle investigators, institutions, and study components assigned are presented in Table 5. The approach utilized Great Lakes experts from various disciplines to maximize data quality within each discipline and allows a research atmosphere for these experts to scientifically interact.

TABLE 4. INVENTORY OF BIOASSAYS

Organism	Assay	End-Point
Bacteria	1. Microtox® 2. Ames Test 3. Glucose Uptake	Metabolism-Physiology Mutagenicity Metabolism-Physiology
Phytoplankton	4. Carbon Uptake	Metabolism-Physiology
Zooplankton	5. Daphnia 6. <u>Ceriodaphnia</u> 7. <u>Daphnia magna</u>	Ingestion Rates Reproduction Survival
Oligochaetes	8. <u>Stylodrilus</u>	Avoidance-Behavior
Insects	9. <u>Chironomus tentans</u> 10. <u>Chironomus tentans</u> 11. <u>Hexagenia</u>	Movement-Behavior Survival, Growth Survival, Growth
Mollusks	12. <u>Lampsilis</u>	PCB Accumulation, Depuration
Fish	13. Channel Catfish 14. Larval Yellow Perch (Passage Study) 15. Rainbow Trout Eggs	Feeding Rates Feeding Rates Survival, Carcinogenicity

TABLE 5. LIST OF COOPERATORS

Clarkson University - Potsdam, New York - DePinto - Sediment Character, Metals, Sorption/Desorption Kinetics
Indiana University - Bloomington, Indiana - Hites - Exploratory Organic Analysis, PAHs
Manhattan College - Bronx, New York - Di Toro - Mathematical and Probabilistic Modeling
Michigan State University - Lansing, Michigan - Giesy - Sediment Bioassay
Ohio State University - Columbus, Ohio - Bedford - Hydrodynamic Sediment Resuspension Probability
Roswell Park Memorial Institute - Buffalo, New York - Maccubbin - Fish Tumor Survey; Sediment Bioassay
University of California - Santa Barbara, California - Lick - Sediment Resuspension, Transport, Disposition
University of Michigan - Ann Arbor, Michigan - White - Sediment and Lower Water Column Bioassay
USEPA, Raytheon Service Co. - Grosse Ile, Michigan - Mullin, Smith - Nutrients, Organics, and Metal Analyses
USEPA, Raytheon Service Co. - Grosse Ile, Michigan - Kreis, Rathbun - Clam Bioaccumulation of PCBs
USEPA, Raytheon Service Co. - Grosse Ile, Michigan - Filkins, Smith - Vessel, Personnel, and Equipment Support
USEPA, Computer Sciences Corp. - Grosse Ile, Michigan - Richardson, McGunagle, Griesmer - IPP; UGLCCS Data Base Management
Michigan Dept. of Natural Resources - Lansing, Michigan - Lundgren - Fish Tumor Research
U.S. Fish and Wildlife Service - Ann Arbor, Michigan - Mac - Fish Shocking/Fish Collection Operations

CONCLUSIONS AND RECOMMENDATIONS

CHEMICAL AND PHYSICAL

1. Sediments of the Trenton Channel, Detroit River, are heavily contaminated with a complex mixture of heavy metals and organic compounds which have resulted from decades of discharge and deposition to the sediment.
2. Heavy metals measured in elevated concentrations were zinc, lead, and copper; other metals detected were nickel, chromium, cadmium and mercury.
3. The spatial distributions of heavy metals in the study area were very similar. Most metal concentrations were highly correlated with one another, indicating a high degree of co-occurrence. All heavy metals were similarly, positively correlated with the organic carbon content of sediments.
4. Twenty-two of the 30 primary IPP stations studied exceeded USEPA dredging guidelines for heavily polluted sediment for at least one metal (primarily zinc). Four stations exceeded guidelines for all metals. Eight stations did not exceed the guidelines for any metal. These results reinforce the highly correlative nature of metals in the sediment and the severe metal contamination in the study area.

5. Interstitial water concentrations of heavy metals did not correlate with concentrations determined from their respective sediments suggesting that factors other than concentration alone affect this relationship.
6. As determined from experimental resuspension procedures, total suspended solids and total metal concentrations in overlying waters were positively correlated to shear stress applied to sediment cores. Additional experimentation indicated that dissolved metal concentrations may increase over time as pH of the overlying water decreases to or below pH 7.5. Flocculation of particles was also related to shear stress; floc size was greater, less dense, and more fragile at lower shear stresses compared to those at higher shears.
7. Of the stations examined for sediment resuspension potential, Stations 34, 53, and 30 exhibited the greatest potential for sediment resuspension. It appears that some of the most contaminated sites have the greatest potential for sediment entrainment to the water column. In the event of storm surges which increase flow rate, volume, resuspension, and subsequently contaminant flux and transport, these sites may have an impact on adjacent and/or downstream sites.
8. PCBs, hexachlorobenzene, PAHs, polychlorinated naphthalenes, polychlorinated terphenyls, and octachlorostyrene were identified in Detroit River sediments. In general, the distributions of organic contaminants were very similar and highly correlated; however, PCBs and PAHs were widely distributed throughout the study area, whereas,

chlorinated naphthalenes and terphenyls were primarily centered in the Trenton Channel.

9. Although concentrations of many organic substances were high, relative to other areas in the Great Lakes, PCB concentrations were generally low; the maximum PCB concentration observed in sediment was 2.88 mg/kg.
10. The most heavily contaminated area observed in the lower Detroit River, in terms of heavy metal and organic contaminants, was the western, nearshore zone of the Trenton Channel for a four-kilometer reach extending from just north of Monguagon Creek southward to Elizabeth Park.

BIOLOGICAL

11. All 30 IPP stations exhibited some degree of toxicity and/or mutagenicity in one or more of the bioassays employed for water, sediment, sediment porewater, and sediment elutriate.
12. Sediment and water samples from the Trenton Channel impaired metabolism, reproduction, feeding, growth, behavior, and survival of a wide range of test organisms representative of the trophic spectrum from bacteria to fish.
13. Ninety-five percent of the 30 primary IPP station sediments tested induced a weak, moderate, or strong mutagenic response in the Ames Test.
14. Bacterial and phytoplankton uptake of glucose and ^{14}C Carbon, respectively, were drastically inhibited when exposed to "clean"

- suspended sediment from a reference site. When exposed to contaminated sediment, uptake was reduced further. Although assays indicated that contaminated sediment inhibited uptake, the mere presence of particles inhibited uptake to a relatively greater extent than did toxicants.
15. Microtox[®] bacterial bioassays conducted at 136 stations indicated that the greatest number of stations with severely toxic sediment porewater were centered in the western, nearshore zone of the Trenton Channel, although a number of other isolated, toxic sites were also identified. Thirty-eight percent of the stations examined were non-toxic or weakly so, indicating that considerable expanses of the lower Detroit River were relatively unimpacted.
 16. Ten of the 30 primary IPP stations examined induced mortality of Daphnia magna; the most lethal stations were in the western Trenton Channel. Feeding of the zooplankter Daphnia pulicaria was also impaired by sediment elutriates.
 17. Ceriodaphnia assays conducted on lower water column samples indicated that survival and reproductive success was significantly inhibited during most times of the year for the four IPP master stations investigated. In the Detroit River passage study, results of this assay indicated that stations just north of the Trenton Channel were more toxic than waters in the Trenton Channel proper.
 18. The various toxic responses obtained from lower water column samples were not necessarily related to sediment toxicity. This indicated that

water column toxicity may be de-coupled from sediment toxicity, and is at least intermittently related to transient factors other than sediment contamination.

19. Species composition, population densities, and diversity of resident macrozoobenthos indicated the degraded nature of the western Trenton Channel. The dominant species observed was the tolerant oligochaete Tubifex tubifex; one site in this region was devoid of benthic fauna. A behavioral assay using an intolerant oligochaete indicated that the test specimens attempted to avoid contaminated sediments and would not burrow or stay burrowed.
20. Sediments from all but five of the 30 primary IPP stations reduced growth of Chironomus tentans. The behavior of C. tentans was also altered when exposed to sediments, where escape responses were more prevalent when compared to normal rest and movement behavior.
21. Based on results from Microtox[®], Chironomus tentans growth, and Daphnia magna lethality assays, it appears that the Chironomus tentans growth assay exhibited the best resolution and discrimination of toxicity within the toxicant concentration ranges observed in the Trenton Channel.
22. Most toxicity tests indicated that the greatest effects were observed in the western nearshore zone of the Trenton Channel and were similar to contaminant patterns in sediment. Conversely, other large expanses of

the study area possessed sediments which were non-toxic or only slightly toxic.

23. Larval yellow perch (Perca flavescens) studies indicated that there was a continuous supply of larvae to the Trenton Channel. The majority of larvae were typically transported along the western sector of the Channel and greatest larval abundance was observed near the confluence with Lake Erie. A spawning/nursery ground for yellow perch was potentially identified in the vicinity of Mud and Grassy Islands near the mid-point of the Detroit River.
24. Stomach content analyses of larval fish indicated that yellow perch collected in the western and main channel portions of the Trenton Channel had ingested relatively less food than those from the eastern zone. Comparisons of larval feeding from the upper to lower reaches of the River were confounded by the entrainment of larval perch from the suspected nursery just north of the Trenton Channel.
25. Tumors and pretumorous lesions were observed in five species of Detroit River fish. Both external (oral/dermal) and internal (liver) tumors were observed. For all fish collected, oral/dermal and liver tumor incidences were approximately 10% each. Tumors were restricted to larger fish in all cases.
26. Tumor incidence varied spatially in the study area. Greatest incidences of external tumors observed in bullhead were at Hennepin Point and upper

Gibraltar Bay: 36.4 and 33.3%, respectively. Conversely, much lower incidence rates were observed at several other sites.

27. Results of the fish tumor surveillance also indicated that tumorous conditions were not confined to bottom feeding/dwelling species. Walleye were observed to have both external and internal tumors. This demonstrated the potential for incidences in top predator, recreational species.
28. Numerous recreational and supporting forage fish species were observed during this study and provide a vital fishery. Compared to other Areas of Concern, fish consumption advisories are few; limited consumption of carp and muskellunge are recommended. The low number of advisories for the Detroit River may be somewhat indicative of the low PCB concentrations observed in the system during this study. With few exceptions, PCB concentrations are driving fish consumption advisories throughout the Great Lakes.
29. Detroit River diving ducks (young-of-the-year) exhibited relatively high PCB concentrations in flesh samples, compared to values typically obtained for Great Lakes fish. Goldeneyes had the highest mean body burden concentrations for the three species analyzed; males generally contained higher concentrations than did females for all species.

GENERAL

30. The multidisciplinary, integrated approach utilized in this study has been decidedly successful and has proved a foundation on which to

develop and establish a comprehensive sediment assessment strategy. The overall intent is to develop a strategy which, with some site-specific modifications, can be applied to any large aquatic system. Although a solid basis for a comprehensive strategy has been developed, methodologies and study components within the strategy must be further refined. The appropriate physico-chemical measurements and bioassays must be identified and developed further. Vertical profiling of contamination and toxicity must also be included in future studies to account for the three-dimensional problem of sediment pollution. Research concerning sediment resuspension and deposition, contaminant flux from the sediment, and the effects of these processes on the water column and in the far-field must be continued.

31. Based on the results of a numerical ranking system and the spatial distribution of contaminants and toxicity in the lower Detroit River, the eight most highly degraded sites were confined to a 4 km reach of the western nearshore zone of the Trenton Channel, extending from just north of Monguagon Creek, southward to Elizabeth Park. Several other numerically defined groups of stations were identified as to their relative degree of degradation, but they were not geographically contiguous and were distributed throughout the study area. As one moved from the western nearshore zone of the Trenton Channel to the north, east, and south, the relative degree of degradation was reduced.
32. Based on the results of the In-Place Pollutants, Detroit River Mass Balance, and Trenton Channel Micro-Scale Mass Balance Studies, it

appears that sediments in the Trenton Channel are influenced by a combination of local sources in the Channel proper and sources from the north. Contaminants in the sediments also appear to be reflective of both past and present inputs to the lower Detroit River.

33. Success of a remedial program for contaminated sediments in the Detroit River is closely linked to the control of point, non-point, and tributary sources. Sediment remediation must be coupled with the NPDES permitting system, wasteload allocations, an indication of reductions compared to historical loads, and/or the likelihood of load reductions in the future. If these factors cannot be incorporated into a remedial strategy or sediment remediation is conducted unilaterally, confidence in success will be diminished because discharges will continue to supply contaminants to the sediment.

34. In a comprehensive, sediment remediation strategy, assessment and wasteload inventories are primary steps. After the areas targeted for remediation have been identified, numerous other steps are necessary. Goals for the remediation must be established prior to actions taken so that success can be evaluated. The appropriate mitigative action or combination of actions must be determined to achieve the remedial goals. The remedial action and its associated activities must be implemented. Finally, the strategy employed for initial sediment assessment must be employed as a post-remedial monitoring plan to determine whether the goals established have been attained.

METHODS

SITE DESCRIPTION

The Detroit River-St. Clair corridor is the sole, navigable link between the upper and lower Laurentian Great Lakes, connecting Lakes Huron and Erie. This system is part of the Great Lakes-St. Lawrence Seaway which includes five Great Lakes, their connecting channels, and the St. Lawrence River. The Seaway extends from Duluth, Minnesota, to Montreal, Quebec, forming a water route of approximately 2200 km. Recreational, commercial, and municipal demand on and use of the system is enormous in terms of fishing, boating, swimming, hunting, shipping, receiving discharges, and as drinking water supplies, to mention a few.

The Detroit River itself is approximately 51 km long and is the terminal passage of the Detroit-St. Clair complex, connecting Lake St. Clair to Lake Erie (Figure 5). The Detroit River is the most-traveled commercial waterway in the Upper Great Lakes. The Detroit River contains numerous islands and the maintained, navigation channel is a series of individual channels winding through the island system. The 8.3-m deep navigation channel runs the length of the Detroit River and serves as the international boundary between Canada (Ontario) and the United States (Michigan).

At the discharge of Lake St. Clair, the navigational channel deflects south of Belle Isle in the Fleming Channel and proceeds along the mid-point

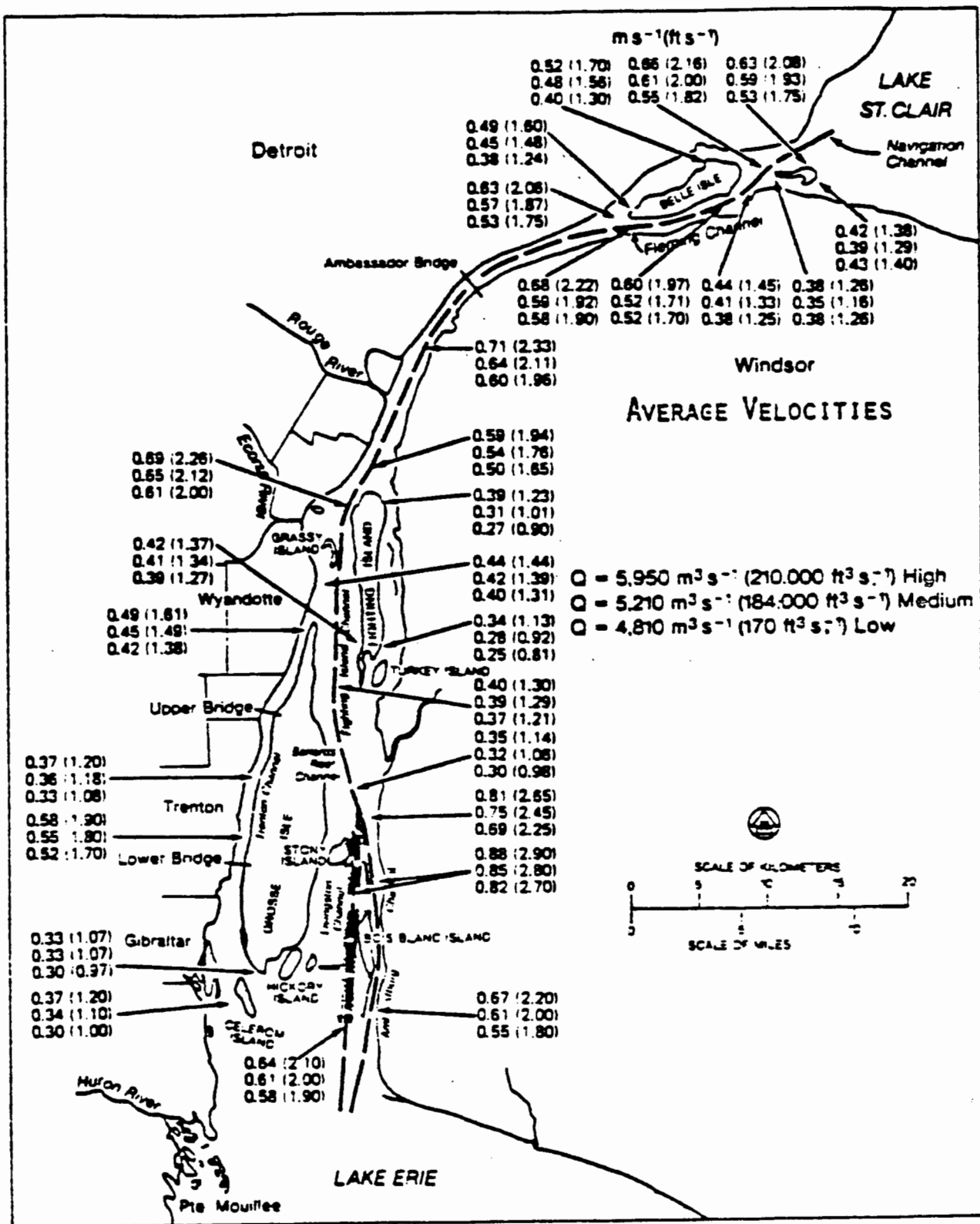


Figure 5. Map of the Detroit River.

of the River to the Fighting Island Channel, just east of Fighting Island and west of Grosse Ile. South of the Ballards Reef Channel, the navigation channel is composed of a series of main and auxiliary channels. The Livingston Channel lies between Stony and Bois Blanc Islands and the Ontario mainland; both channels open to the western basin of Lake Erie.

Of particular interest in this study is the Trenton Channel which lies on the opposite side of Grosse Ile from the navigation channel. The Trenton Channel runs the length of Grosse Ile and is formed by the Island and the Michigan mainland. The Trenton Channel extends for approximately 13 km from its headwaters at Point Hennepin, the northern-most tip of Grosse Ile, to a transect from Gibraltar, Michigan, to the lowermost portion of Grosse Ile. The confluence of the Detroit River and Lake Erie lies immediately to the south. Discharge from the Detroit River to Lake Erie ranges from $4,810 \text{ m}^3 \text{ s}^{-1}$ to $5,950 \text{ m}^3 \text{ s}^{-1}$ (low and high flows, respectively), the majority of which flows from the east channel (75-80%), with the remainder (20-25%) from from the Trenton Channel.

The Trenton Channel ranges from 1 to 10 m in depth in the main portion of the Channel. Greatest depths are generally observed in the headwater area of Hennepin Point and shallowest areas near Gibraltar. Channel width tracks inversely to depth, from 0.25 km in the Hennepin Point area to 1.2 km near the outlet. The mid-portion of the Channel is generally underlain with glacial boulders, cobble, and gravel whereas both channel margins generally have sedimentary deposits. The most extensive sedimentation zones occur at the southern end of Grosse Ile and in the Celeron Island area (Fallon and Horvath, 1983). A sedimentation zone is present at the northern-most tip of

Point Hennepin and a moderately large zone lies along Grosse Ile just to the south which supports an extensive macrophyte bed during the summer period.

There are approximately 70 permitted discharges to the Detroit River. The Rouge River and Ecorse River discharge to the Detroit River just north of the Trenton Channel. The Rouge River carries the discharge of the Detroit Wastewater Treatment Plant, the largest of its kind in the United States. In addition to discharges, Zug, Mud, Grassy, and Fighting Islands, and Point Hennepin, have been used as industrial or dredged material disposal sites. On the Michigan mainland, the cities of Wyandotte, Riverview, Trenton, and Gibraltar abut the Channel. The Trenton Channel also serves as a receiving body for numerous industries which include, in alphabetical order: BASF Wyandotte Corporation, Chrysler Corporation, Detroit Edison Company, Edward C. Levy Company, Firestone Steel Products Company, McLouth Steel Corporation, Monsanto Company, Pennwalt Corporation, and Wyandotte Cement, Inc. Additionally, waste disposal sites and landfills are along the shoreline. The shoreline also supports numerous recreational marinas.

FIELD AND ANALYTICAL TECHNIQUES

A suite of chemical, physical, and biological determinations were conducted on sediments, sediment interstitial waters, sediment elutriates, sediment cores, lower water column samples, and biota. Physical characterization of the sediments as well as heavy metal and organic compound concentrations were determined; heavy metal analyses were also conducted on sediment porewaters. Heavy metals, nutrients, and physico-chemical characteristics were determined on lower water column samples. Additionally, a series of in-situ and laboratory studies concerning sediment resuspension

potential, flocculation, settling velocity, and shear-stress potential and the physico-chemical characters governing these processes were conducted.

A series of bioassays were conducted using sediment, sediment porewaters, sediment elutriates, and samples from the lower water column; a list of assays is presented in Table 4. A fish tumor survey and a larval fish passage study were also completed during the course of the project. In addition to the bioassays and fish studies conducted, contaminant body burden concentrations were determined for young-of-the-year diving ducks and macrophytes.

The following review of field and analytical techniques is intended to provide an overview of methods used in the study. For a complete account of techniques, refer to the appropriate appendices (Appendices A-V).

Sediment: Collection, Processing, Characterization and Chemical Analysis

Thirty primary sediment stations were sampled during the summer of 1986 for an intensive study of in-place pollutants in and proximal to the Trenton Channel, Detroit River (Figure 6 and Table 6). The study area extended from the north-eastern side of Fighting Island to the River confluence with Lake Erie. Stations were selected to provide a spatial and a suspected contamination gradient in the study area. Studies were coordinated in time and space so that as many analyses as possible could be conducted on the same parcel of sediment to obtain the most complimentary data set possible.

Sediment samples were obtained using a Ponar[®] grab sampler. At the time of collection, temperature, conductivity, pH, and dissolved oxygen of the lower water column were determined using a HYDROLAB[®] Submersible DataSonde. The above data, meteorological conditions, and sample types collected were

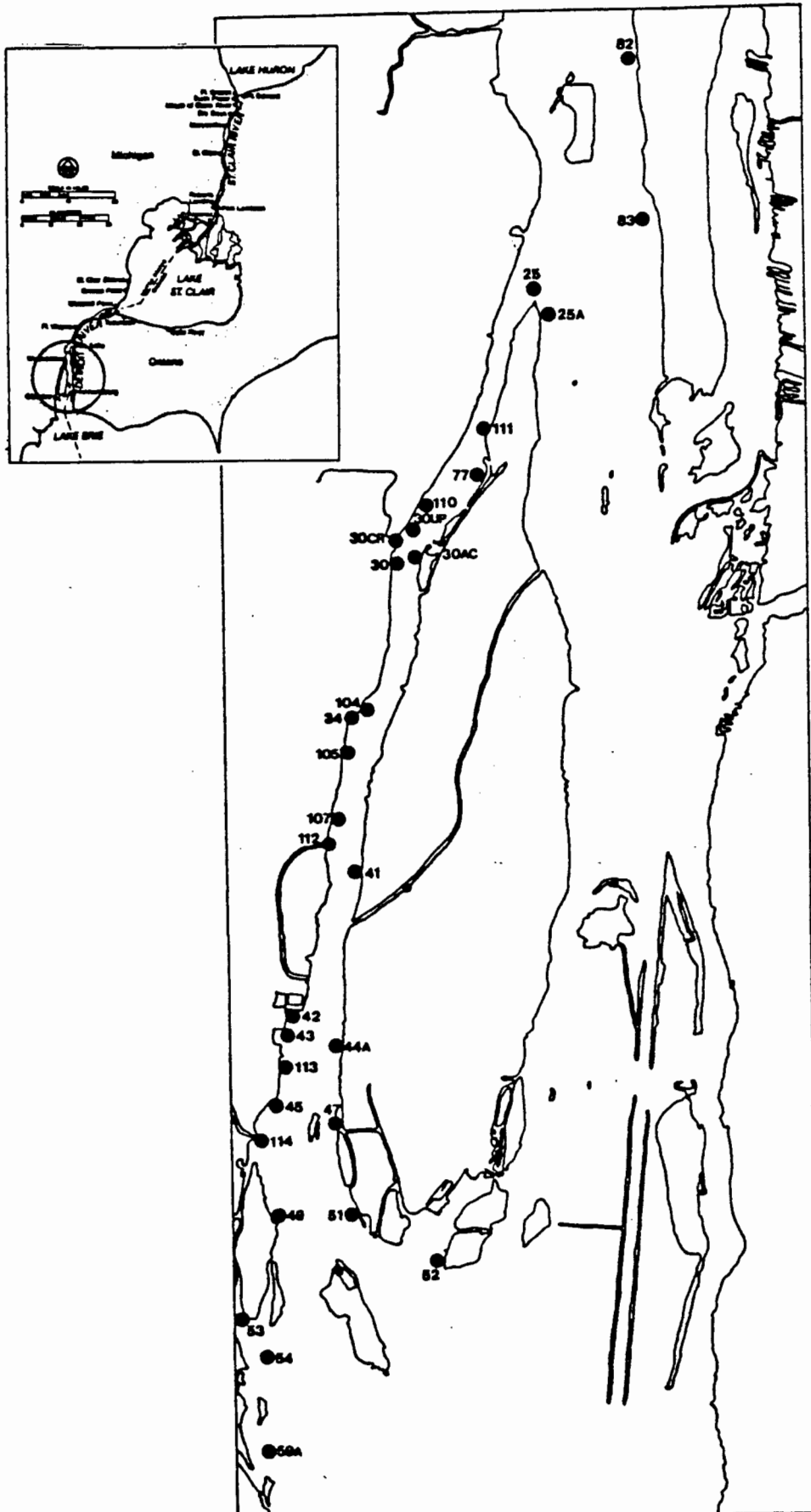


Figure 6. In-Place Pollutants Study Station Array, 1986.

TABLE 6. IN-PLACE POLLUTANTS STUDY STATION COORDINATES.

STATION	LATITUDE	LONGITUDE
83	4212.74	8307.55
54	4204.45	8311.25
47	4206.13	8310.52
44A	4206.75	8310.47
113	4206.61	8311.03
52	4505.17	8309.56
51	4205.51	8310.35
45	4206.34	8311.12
114	4206.13	8311.29
111	4211.25	8308.95
59A	4203.83	8311.20
53	4204.73	8311.46
49	4205.47	8311.16
43	4206.82	8311.04
30AC	4210.25	8309.64
25A	4212.02	8308.44
41	4208.09	8310.25
77	4210.05	8309.12
25	8212.13	8308.54
110	4210.81	8309.57
30UP	4210.48	8309.79
112	4208.19	8310.57
30CR	4210.41	8309.88
30	4210.28	8309.82
42	4206.98	8310.90
104	4209.15	8310.25
105	4208.89	8310.39
107	4208.45	8310.50
34	4209.11	8310.31
82	4213.83	8307.62

recorded on field collection sheets. Each sediment sample was homogenized, placed in acid-rinsed containers, and stored in the dark on ice. Upon return to the laboratory, bulk sediment subsamples were placed in glass containers. Sediment porewaters were obtained by a combination of centrifugation and filtration. Bulk sediment and porewater subsamples were distributed to the research team for various physical, chemical, and biological analyses.

Physical characteristics of sediments determined were moisture content, loss on ignition, specific gravity, and particle size distribution. Moisture content and loss on ignition were determined by weight after drying and combustion, respectively. Specific gravity was determined using pycnometric methods and particle size distribution was measured by wet-sieving samples under vacuum, with and without a dispersing agent. Mesh sizes used were 710, 500, 355, 250, 180, 125, 90, 63, 20, 10, 5 and 1 micrometers.

Suspended solids were determined by vacuum filtration through a 0.45 cellulose membrane filter. The filter and retained solids were dried, dessicated, and weighed. Total organic carbon and total inorganic carbon were determined by wet combustion and gravimetric methods (Black, 1965).

Total metals sought in sediment and porewater samples included zinc, chromium, copper, lead, nickel, cobalt, mercury, and cadmium. Samples were digested with nitric acid as found in EPA Method 3020. For heavy metal analyses of bulk sediment, the digested sample was analyzed by flame atomic absorption using a Perkin-Elmer[®] Zeeman/5000 Atomic Absorption Spectrophotometer. The Zeeman/5000 was set in the appropriate mode for each

[®]Reference to trade names does not imply endorsement by the U.S. Government.

specific metal, calibrated, and analyses of blanks, standards, and replicates were conducted. The National Bureau of Standards river sediment #1645 was carried through the process and used as an accuracy quality control check. Porewater samples were also analyzed on the Zeeman/5000 which is equipped with a Perkin-Elmer® AS-40 Auto-Sampler and a HGA-400 Graphite Furnace for use in furnace mode. Calibration was accomplished and appropriate blanks, standards, and replicates were also analyzed with porewater samples. Bulk sediment and porewater analyses were conducted by both Clarkson University and the Large Lakes Research Station.

An Orion® Research Digital Ionalyzer (Model 501) and a Sargent Welch® electrode were used for pH measurements after proper calibration with buffers. Sediment cation exchange capacity was determined through a two-step procedure. Cation exchange sites were saturated with Na, using an ethanol solution of 0.4N NaOAc - 0.1N NaCl titrated to a pH of 8.2, followed by extraction with 0.5 MgNO₃. Total Na and Cl in the extracted solution were determined by flame atomic absorption.

For congeneric PCB analyses, samples were mixed with anhydrous sodium sulfate and Soxhlet extracted with n-hexane and dichloromethane for 48 hours. The sample extract volume was reduced by boiling off the solvents and cleaned of interfering compounds by gel permeation chromatography (GPC). The GPC eluants were reduced under nitrogen gas, brought to volume with cyclohexane (CX), reduced again, and brought to volume with 2,2,3-trimethylpentane (TMP). All analyses were performed on Varian Model 3700 capillary column gas chromatographs fitted with dual Ni⁶³ electron capture detectors, autosamplers, and 60 m X 0.25 mm (i.d.) bonded DB-5 fused

silica columns. Individual congeners were identified with reference to a standard mixture of Aroclors.

For polycyclic aromatic hydrocarbon (PAH) analyses and screening for other compounds, sediment samples were Soxhlet extracted for 24 hours with propan-2-ol and extracted for an additional 24 hours with dichloromethane. Extracts were reduced by rotary evaporation and solvent-exchanged with n-hexane. Samples were loaded on the column and eluted sequentially with n-hexane, 10% dichloromethane in hexane, 100% dichloromethane, and methanol; in some cases, additional clean-up was required. Sediment fractions were screened using a Carlo Erba[®] Fractovap 4160 series GC with dual electron capture and flame ionization detectors, in series, to determine relative compound concentrations. Samples were separated on a J&W Scientific[®] fused silica capillary column, coated with a bonded, cross-linked DB-5 liquid phase.

Electron capture, negative ionization GC/MS analyses were performed with a Hewlett-Packard[®] 5985B GC/MS system equipped with a 30 m x 0.25 mm (i.d.) DB-5 fused silica capillary column; helium was used as the carrier gas. Methane was introduced into the source, the source was regulated to an ion pressure of 0.4 torr, and held at 100°C. A range of 50-750 amu was scanned every 1.4 seconds, emission current was approximately 200 μ A, and electron energies were approximately 200 eV.

Polycyclic aromatic hydrocarbons were identified and quantified on a Hewlett-Packard[®] 5995 GC/MS operated in the electron impact mode and equipped with a Hewlett-Packard[®] 25 m x 0.25 mm SE-54 fused silica capillary column. Helium was used as the carrier gas and temperature was increased from 30 to

290°C at 10°C/minute. Electron energies were approximately 70 eV. Ratios of PAH to perdeuterated PAH were used to calculate PAH concentrations.

Procedural blanks were carried through extraction, isolation, and analysis, and final results corrected for blank contribution, if necessary.

Sediment Resuspension Potential and Related Processes

A Coastal[®] Data Acquisition and Retrieval Tower System was deployed at four sites in the Trenton Channel by scuba diver. The main probe of the system is a 3 MHz Edo Western[®] Profilometer which sends a 10 μ s pulse of MHz sound through the water column. The signal is digitized into 110 readings along the beam path and the instrument receives various echoes returning from suspended particles and from bottom reflectance. Profiles are taken 32 times per second and are averaged to produce one-second profiles. The lower current meter, mounted 25 cm above the bottom, measures the downstream horizontal and vertical components of water velocity. The upper current meter, mounted at 1.1 m above the bottom, recorded the downstream horizontal and cross-stream horizontal components. A Sea Tech[®] optical turbidimeter monitors water clarity and a pressure transducer records water level fluctuations at the surface simultaneous to other measurements.

Field experimentation is used to verify sediment resuspension potential, expressed probabilistically, from flow and meteorological data. Historical flow data have been obtained from the U.S. Army Corps of Engineers-Detroit and daily weather data from the National Oceanic and Atmospheric Administration for the period 1971-1983. Statistical methods include determination of geometric distribution, poisson distribution, normal and

lognormal distributions, extreme value distributions, and risk and exceedance probability.

Experimental field and laboratory studies for measuring sediment resuspension and associated properties were conducted using portable and laboratory shaking apparatuses (Tsai and Lick, 1986). The shaker consists of a cylindrical chamber inside of which a horizontal grid oscillates vertically. The shaker grid is a 0.6-cm thick plexiglass disk which has a diameter of 11 cm and is perforated with 1.2-cm diameter holes; distance between neighboring holes is 1.5 cm. The grid is powered by a variable speed motor which is coupled by a drive disc to the motor shaft, a linkage bar, and drive rod. The linkage bar is set 1.27 cm off center of the disc to create an up and down motion of 2.54 cm. The shaker chamber is made of acrylic tubing and is 30.5 cm in length with an inside diameter of 11.7 cm. Sediment cores for resuspension tests were collected in the cylindrical chamber by scuba diver; overlying water was retained in the chamber for the study. Grid oscillation frequency created shear-stresses of 2.5 and 5.0 dynes/cm² and were tested for various time lengths and sediment concentrations. Turbulence created by the oscillating grid in the overlying water causes sediment resuspension and is proportional to the frequency of grid oscillation. Equivalent shear stresses created by the oscillating grid were determined by comparison of sediment concentrations in the shaker and an annular flume. Suspended solids concentrations, pH, and total and dissolved heavy metals were measured for these experiments.

Flocculation experiments were conducted using a Couette-type viscometer which consists of two concentric cylinders, made of acrylic tubing, which

rotate relative to one another. The main advantage of this apparatus is the ability to generate a uniform velocity shear in the fluid in the annular gap between cylinders. Viscometer length is 25.4 cm; the outer radius of the outer cylinder is 2.5 cm and the outer radius of the inner cylinder is 2.3 cm. The inner cylinder is fixed to a steel shaft through which the viscometer is horizontally clamped to two anchor seats. A series of intake ports and an endpiece stopcock allow dye injections and air bubble release, respectively. Coupling gears on the cylinder endpiece and on the motor shaft allow the viscometer to be rotated by a 1/4 horsepower motor. Apparatus dimensions allow a theoretical maximum, mean shear-stress of 10.5 dynes/cm²; turbulent flow was found at stress greater than 9.2 dynes/cm² and laminar flow below this value. Well-characterized, fine-grained sediments were introduced into the viscometer after disaggregation. The viscometer was brought to a speed corresponding to the desired shear-stress which was usually 1, 2, or 4 dynes/cm². Tests were conducted at these stresses for various time intervals and sediment concentrations. Samples for floc measurements were taken from each combination of stress, time, and sediment concentrations tested. Floc sizes were measured using a Malvern[®] Particle Sizer 3600E which utilizes the Fraunhofer diffraction principle for particle size distribution measurements.

Lower Water Column Sample Collection and Analyses

In addition to sediment sample collections, water samples were collected from the lower water column for several bioassays. Four master stations were chosen for intensive study, these include: 30CR - Monguagon Creek, 34 - Black Lagoon, 53 - Gibraltar Bay, and 83 - Fighting Island. Near-bottom

water collections were conducted from June 1 - November 23, 1986, during eleven sampling periods. Water samples were obtained from approximately 0.5 m above the river bed. A 4-m pole was mounted 0.5 m above a wooden platform which was lowered until the platform rested on the river bottom. Water was pumped shipboard through a hose attached to the pole using a portable electric pump. Samples were placed in acid- and deionized, distilled water-rinsed polyethylene bottles and stored on ice. Specific conductance, pH, dissolved oxygen, and temperature were measured in the field using a HYDROLAB[®] DataSonde. Samples were collected for heavy metals, nutrients, and suspended solids analyses and distributed to various laboratories for bioassays and analyses.

Station 83 at Fighting Island was selected as a Detroit River reference site for both lower water column and sediment bioassays. Several assays report results relative to results obtained at this station. The rationale for selecting this station was based on the observation that Hexagenia limbata and Chironomus tentans occurred in the sediments at this site and that conditions were favorable or at least sufficient for these desirable species to survive. The observation that this site was at least only moderately impacted was reconfirmed from the results of reconnaissance assays which indicated little or no toxic effects of sediments. In addition to this reference site, a control site was established in Lake Michigan for some assays. This station was located 10 km west of Bridgman, Michigan. Control water and sediments were used from this site. Sediment was collected at 42 m depth.

Bioassays

The Microtox[®] bacterial bioluminescence assay was conducted on sediment porewaters using standard procedures. Serial dilutions of porewaters were used for exposure and added to aliquots of the laboratory-cultured bacterium, Photobacterium phosphoreum, to provide dose-response functions. Toxicity was inferred from a decrease in light emission corrected for gamma distribution. A Microtox[®] Model 2055 Toxicity Analyzer was used to detect light intensity changes upon exposure. Results were expressed as concentrations of porewater to elicit EC10 and EC50 responses compared to the reference.

Mutagenic potential of sediments was tested using the Salmonella/-microsome assay known as the Ames Test. Sediment samples were Soxhlet extracted with dichloromethane and then solvent-exchanged into dimethyl sulfoxide (DMSO). Extracts were diluted in a serial sequence to generate dose-response functions. Extract was mixed with bacterial cultures and agar containing histidine and biotin and then poured into glucose-base agar plates and incubated for two days. Buffer solution containing rat liver homogenate was added for S9 metabolic activation. After incubation, the number of revertant colonies (His⁺ revertants) were determined and expressed as His⁺ revertants/g dry weight sediment.

Bacterial and phytoplankton bioassays were conducted on control sediment and water, and on contaminated sediment, porewater, and elutriate matrices. Bacterial metabolism was measured by uptake of ³H glucose or ³H adenine and phytoplankton photosynthesis by uptake of ¹⁴C bicarbonate. After incubation in all tests, cells were filtered and radioactivity determined using a scintillation counter. Bacterial biomass estimates were obtained by

staining with acridine orange and counts by epifluorescent microscopy. Chlorophyll a was extracted with acetone and measured fluorometrically for phytoplankton biomass. Exposure to sediment and sediment elutriate were conducted using a rotational device (at 1 rpm) to suspend sediment. Differences in the techniques lie in the time at which the radioisotope was introduced. For sediment exposure, the radiolabel was introduced upon initiation and during suspension, whereas for elutriate exposure, the radiolabel was added after sediment suspension. Dose-response relationships were obtained for sediment at exposure concentrations of 0, 12, 120, and 1200 mg/L wet weight. Porewater was added in concentrations of 0.5, 1.0, and 10.0 mL/L for dose-response. Bacteria samples were incubated for two hours in darkness and phytoplankton for four hours with light saturation

The effects of sediment on phytoplankton-zooplankton interactions were examined using Cryptomonas erosa var. reflexa and Daphnia pulicaria. Various wet-weights of sediments were introduced to known numbers and aliquots of phytoplankton and zooplankton to obtain dose-response curves. Treatments were performed at 16°C, light-saturation conditions, and test chambers were rotated at 1 rpm to maintain sediment suspension. A series of background experiments were performed to determine the effects of various sediment concentrations on algal growth and Daphnia feeding independently. These results allowed an interpretation of these processes, simultaneously, in the primary bioassay. Zooplankton growth rates, clearance rates, and ingestion rates were determined for the assay for various elutriate concentrations at various sites. Test duration was approximately 24 hours and results were interpreted relative to controls and independent measurements of processes.

Acute lethality of Daphnia magna was measured upon exposure to sediment porewaters. D. magna neonates used in the assay were less than 24 hours in age and were laboratory-reared on Chlamydomonas reinhardtii. Assay duration was 48 hours and mortality recorded in each treatment which were conducted in a dilutional series. Results obtained were dose-response functions and were expressed as concentrations of porewater to elicit a LC10 or LC50 response.

The Ceriodaphnia seven-day chronic bioassay was conducted using near-bottom water samples from the four IPP master stations and a Lake Michigan control. Cultures were maintained at 25°C and fed 0.25 mL of yeast suspension (each) per day. Prior to the bioassay, several adults were isolated to parthenogenically produce a sufficient number of uniform-age neonates for the assay. Neonates (age of 8-10 hours) were used as test specimens. Fifteen milliliters of test water were placed in beakers and a single neonate transferred to the test solution; ten replicates were used for each treatment. Neonates were transferred to new test water on days 3 and 5 of the assay. Percent female survival, total number of young produced per female, and number of broods per female were tabulated after seven days. Results were averaged over the total number of females in each treatment and were compared to control results.

Chironomus tentans was used as a test specimen in a 10-day growth bioassay. C. tentans cultures were maintained using TetraFin® flake fish food to produce 13-d post-hatch instars (second instars) for bioassays. Individual instars, in replicates of 15, were exposed to bulk sediment from the study area for 10 days. At the end of the exposure period, growth,

expressed as weight, was calculated. Results were reported as percent reduction in growth, relative to the reference site.

Chironomus tentans was also used as a test specimen in an optical-fiber, light-interruption bioassay. Chironomids were allowed to enter and establish a living space in 1 mm i.d. glass tubes and were restricted to the tube by glass threads. The tubes were transferred to small aquaria containing test solutions/suspended sediments. The tube with larva was placed directly over an optical-fiber bundle and between the bundle and a red LED. Larval movement was monitored by the amount of light received/interrupted by the bundle, was amplified, and recorded on a chart recorder. Respiratory undulations, turning, crawling movements, and rest were the behavioral responses recorded. These were compared to control responses.

A sediment avoidance bioassay was conducted using Stylodrilus heringianus. The assay was conducted on control sediment, reference sediment and sediment from master stations. Test sediment (15 mL) and enough station water to fill the beaker were placed in a 30 mL beaker. Ten Stylodrilus specimens were added to each beaker and ten replicates were used for each test. The number of worms remaining on the sediment surface was recorded every six to eight hours over a 48- or 96-hour period. If mortality occurred, it was also noted.

Newly-hatched channel catfish were exposed to control sediment and sediment from the master stations at concentrations of 0.1, 0.6, and 1.1 g/L wet weight. For each assay, two replicates were used, each containing two to four fish and 20 C. tentans larvae. Test chambers were oxygenated, sealed and then rotated at 1 rpm for various time periods. Fish were sacrificed,

stomachs dissected, and chironomid head capsules enumerated for feeding estimates. A similar assay was performed for porewater. Field bioassays were conducted using a 20-cm diameter PCV pipe as a confinement chamber. Nitex[®] screen covered the openings of the chamber for exposure to water and sediment; chambers were placed on the sediment and just below the water surface at four stations; the test period was four hours. Each chamber contained eight or nine channel catfish and 100 chironomid larvae. Results were expressed as feeding rate (chironomids eaten per hour) and fish mortality was recorded when observed.

Rainbow trout eggs were used to determine the carcinogenic potential of sediment. Sediment extracts were prepared as described for the Ames Test. Serial dilutions of extract were injected into late-eyed stage rainbow trout eggs using a microinjection technique; extracts were injected directly into the yolk sac two to seven days prior to hatching. Each egg received a 0.9 μ L injection of DMSO containing the sediment extract. Eggs were incubated and mortality of eggs and fry and fry hatch were monitored through the swim-up stage. At one-year post injection, survivors were sacrificed and examined for external and internal lesions. Livers were fixed in Bouin's fixative, sectioned, dehydrated, and stained with hematoxylin and eosin. Liver neoplasms were recorded from microscopic examination.

Fish Tumor Survey

Fish were obtained from six sites in the lower Detroit River for fish tumor studies. Four hundred and fifty-seven specimens were collected by electrofishing and subsequently autopsied. Species collected included brown bullhead, white sucker, redhorse sucker, walleye, and bowfin. Individuals

were measured, weighed, examined for external lesions and necropsied for internal abnormalities. During necropsy, sex was determined, selected tissues were removed for histological examination, and bile was removed from the gall bladder for further analysis.

Tissues for histological analyses were trimmed, dehydrated, and embedded in paraffin. Sectioned tissue was mounted on microscope slides, stained with hematoxylin and eosin, and examined using light microscopy. Bile samples were analyzed for benzo[a]pyrene (BaP) metabolites using a Perkin-Elmer[®] 3B liquid chromatograph equipped with a Vydac[®] TP201 reverse phase C18 column. After eluting the column with a series of distilled water/acetic acid and methanol solvents, metabolites were detected using a fluorescence spectrophotometer (Perkin-Elmer[®] 650-10S) set for detection of hydroxyl metabolites of BaP. Peak areas were integrated using a Hewlett-Packard[®] 3100 system integration and converted to BaP equivalents.

Larval Fish Passage Study

The larval fish passage study was conducted on May 17-18, 1986 and spanned the entire Detroit River system, from the outlet of Lake St. Clair to the confluence with Lake Erie. A finned-drogue was used to trace water mass movement through the length of the system to follow larval fish and zooplankton passage. Data were collected from each side of and the mid-portion of the River at 17 transects approximately 2.5 km apart.

Physico-chemical parameters determined were temperature, dissolved oxygen, alkalinity, conductivity, hardness, chloride, pH, suspended solids nitrate + nitrite N, ammonia, and silica. Physical factors were measured using a HYDROLAB[®] Submersible DataSonde; chemical measurements were

determined using a Technicon® Autoanalyzer II and standard colorimetric methods. Biological parameters included bacteria, phytoplankton, chlorophyll a, zooplankton, and fish larvae. The Ceriodaphnia seven-day bioassay was also conducted at five sites through the length of the River and samples for heavy metals analyses were collected from these five sites.

Larval fish were collected by towing a bow-mounted, 0.5-m diameter, 0.363-mm mesh plankton net for 10 minutes. The net sampled the upper 0.75 m of the water column and was deployed against the current. A Rigosha® flowmeter was attached to the net mouth to calculate water volume filtered. Zooplankton were collected using a 0.25-m diameter, 0.156-mm mesh plankton net which was hauled vertically. In addition to the samples collected on transects, larval fish and zooplankton samples were taken at a fixed location from the free bridge at Grosse Ile. Samples were collected once per hour from the east, west, and mid-portion of the Trenton Channel from the free bridge, using the same procedures as noted above.

Larval fish were removed from each sample, enumerated, identified, and measured (to the nearest 1.0 mm) using a binocular microscope. Densities (number/1,000 m³ water) were calculated from counts and flowmeter readings. To determine feeding patterns of yellow perch, stomach contents were teased from the stomachs and counts and measurements of zooplankton and other prey were made. A qualitative estimate of stomach fullness (% total) was also recorded for each specimen.

RESULTS

SEDIMENT CHARACTERIZATION AND HEAVY METAL CONCENTRATIONS

A wide range of sediment types, grain sizes, organic carbon concentrations, and heavy metal concentrations in bulk sediment and porewater was observed in the Trenton Channel. Sixty percent of the sites investigated possessed 50% or more fine-grained sedimentary material which passes through a 1 mm mesh screen. Although no clear particle size distribution pattern was discerned, stations with a greater percent fine-grained material were centered in the northwest sector of the study area.

Eight primary heavy metals were sought and detected at all sites. Highest mean concentrations were recorded for zinc, lead, and copper. Nickel, chromium, cobalt, cadmium, and mercury concentrations were detected in relatively lower concentrations. Concentrations varied widely over the study area, for example, zinc ranged from 16 to 4080 mg/kg and lead from 6 to 1592 mg/kg. Greatest heavy metal contamination was observed in the vicinity of Monguagon Creek and southward along the western, nearshore zone of the Trenton Channel. USEPA dredging guidelines (IJC, 1982) for heavily polluted sediment were exceeded in many cases, for example, 22 of the 30 stations had zinc concentrations greater than 200 mg/kg. Of the 30 stations investigated, 19 for lead, 18 for nickel, 17 for copper, 12 for cadmium, and 5 of 30 for chromium exceeded their respective guidelines. Four stations exceeded the

guidelines for every metal (Stations 30UP, 34, 107, and 111). Eight stations did not exceed the respective guidelines for any metal.

Most metals were significantly ($p < 0.05$), positively correlated among themselves indicating a high degree of co-occurrence. Zinc and cobalt were a notable exception and were not significantly ($p < 0.05$) correlated. All total metals were also significantly ($p < 0.05$), positively correlated with total organic carbon and loss on ignition. As may be expected, total organic carbon concentrations were greatest in the Monguagon Creek area and southward. Cation exchange capacity did not correlate well with total sediment metal content.

Heavy metal concentrations in porewater did not follow the general trend observed in bulk sediment. Zinc, copper, cadmium, and nickel concentrations were generally the highest in porewater, whereas lead, chromium, and cobalt were in relatively lower concentrations. All metals, except for cobalt, were detected in all porewater analyses. Cobalt was not detected at four stations and was observed in very low concentrations at many sites. Heavy metal concentrations in porewater and bulk sediment were not associated on a site-by-site basis. In fact, no significant ($p < 0.05$) correlations between porewater and bulk sediment concentrations were observed, suggesting an uncoupling of these concentrations, and that factors other than sediment concentration alone, control porewater concentrations.

Results of hierarchical cluster analysis indicated similarities in metal concentrations in the Monguagon Creek area and southward; these were regarded as the most contaminated sediments. Generally, stations located along the

Grosse Ile nearshore area, and extreme northern and southern portions of the study area exhibited the least contamination.

Factor analysis supports some of the correlations and observations made earlier. Seven factors accounted for 68.2% of the total variance; the first two factors accounted for 38.6% and the remaining five for 29.6% of the variance. The first factor underscores the association between total metal concentrations in sediment, organic carbon, loss on ignition, and moisture content. The second factor reflects the association of sediment, inorganic carbon, fine-grained sediments, and cation exchange. Greater surface area for cation exchange in regard to fine-grained particles would explain this association. The remaining factors involved mixed associations with porewater concentrations and several other variables that were not readily identifiable.

A complete account of heavy metal data and physical characteristics can be found in DePinto et al. (1987), Appendix A, and in Appendix C.

ORGANIC CONTAMINANTS

The major chlorinated compounds and compound classes identified in Detroit River sediment extracts include: polychlorinated biphenyls (PCBs), hexachlorobenzene, polycyclic aromatic hydrocarbons (PAHs), octachlorostyrene, polychlorinated naphthalenes (PCNs; Halowaxes), and a series of polychlorinated terphenyls (PCTs). Greatest concentrations of these compounds are centered in the vicinity of Monguagon Creek and extended southward along the western shoreline of the Trenton Channel. General distribution of the compounds indicated that PCBs, PAHs, and hexachlorobenzene were widely distributed throughout the study area and were

detected in various concentrations in all samples analyzed. Conversely, chlorinated terphenyls and naphthalenes were primarily restricted in distribution to the Trenton Channel. In general, the distributions of most organic contaminants indicated a high degree of co-occurrence throughout the study area.

Total PCB concentrations ranged from 0.01 to 2.83 mg/kg. Highest concentrations were observed at Stations 43, 105, 110, 42 and 112, respectively (all greater than 1.5 mg/kg); these stations lie in the western nearshore zone of the Trenton Channel. Concentrations of PCBs in the lower Detroit River do not appear to be high, relative to other areas in the Great Lakes. Hexachlorobenzene concentrations ranged from 0.0004 to 1.8427 mg/kg. Highest concentrations were observed at Stations 110, 112, and 107 in the Trenton Channel. Octachlorostyrene was observed in very low concentrations at only a few stations.

Fifteen polycyclic aromatic hydrocarbons (PAHs) were quantified from sediment extracts. Of the individual PAH isomers quantified, fluoranthrene, pyrene, phenanthrene, chrysene, benzo(a)pyrene, benzo(b)fluoranthrene, and benzo(a)anthracene, respectively, were in greatest concentrations. Individual PAH concentrations ranged from 4 to 22,000 ng/g dry weight; total PAH concentrations ranged from 350 to 133,000 ng/g dry weight. Correlation coefficients indicated a high degree of co-occurrence (in terms of concentration) among individual PAHs and between individual PAHs and total PAH concentrations; all correlations were significant ($r = 0.969$; $p < 0.01$; $n = 120$). Greatest concentrations occurred at Stations 110, 112, and 30CR, respectively. Generally, greatest PAH concentrations were observed in the

upper Trenton Channel but not in a distinct distribution or gradient. Many of the greatest concentrations were observed in the vicinity of industrial sources.

Relative amounts of each PAH isomer were similar across a wide range of absolute concentrations. In addition to being compositionally uniform, relatively large concentrations of photo-reactive PAHs (e.g., anthracene and benzo(a)anthracene) suggests sources other than combustion-derived atmospheric particulates. Trenton Channel sediment ratios for phenanthrene/anthracene and benzo(c)pyrene/benzo(a)pyrene are 2.9 and 0.93, respectively. In sediments and atmospheric particulates collected at remote sites, phenanthrene/anthracene and benzo(c)pyrene/benzo(a)pyrene ratios are 16 and 2, respectively (McVeety, 1986; Furlong et al., 1987b). These ratios reflect the relatively short photolytic half-lives of anthracene and benzo(a)pyrene upon exposure to sunlight (Behymer and Hites, 1985). Results indicate relatively high concentrations in the Trenton Channel and together with the sediment ratios calculated, suggests a relatively high yearly input of PAH to the system from multiple sources.

Intensive analyses were conducted on Station 30CR to determine other potential contaminants present in the Trenton Channel. Analysis indicated the presence of steriods, alkyl substituted naphthalenes, phthalates, carboxylic acids, and volatile halogenated species. This analysis suggests the wide diversity of organic contaminants which may be present in the system and may potentially impact biota.

For a complete discussion of organic contaminant analyses, refer to Furlong et al., (1987a), Appendix E, and Appendix F.

FIELD AND LABORATORY SEDIMENT RESUSPENSION EXPERIMENTS: TOTAL SUSPENDED SOLIDS AND HEAVY METALS

Results of artificially disturbed sediment core experiments, using a shaker apparatus, revealed a number of resuspension characteristics concerning suspended solids, total and dissolved metals, pH, shaking frequency, and time.

Suspended solids concentrations were positively correlated ($p < 0.05$) with the frequency of shaking which simulated shear stress. Total suspended solids concentrations increased rapidly in the overlying water during the first five minutes; steady state concentrations were generally reached after 10 minutes of agitation/oscillation and solids concentrations then decreased slowly over time. This was observed for all oscillation frequencies ranging from 2.5 to 5.0 dynes/cm². The greater the frequency, the greater amount of sediment resuspension was observed in all cases, until steady state was attained. Suspended solids concentrations were approximately an order of magnitude greater between the frequencies of 2.5 (140 to 1100 mg/L) and 5.0 dynes/cm² (2500 to 7200 mg/L). Replicate tests indicated good reproducibility of experimental results. A few differences were observed in replicate tests but were assumed to be due to spatial and vertical heterogeneity of sediments.

Significant differences ($p < 0.05$) were observed among sites indicating that the physical characteristics of sediment and the past deposition of contaminants were different at each site. Sediment composition varied substantially but all sites were considered fine-grained. Comparing steady state concentrations of suspended solids, it appeared that Stations 34, 53,

and 30 exhibited the greatest potential for resuspension. Conversely, Stations 46, 53A, and 42 showed the lowest potential for resuspension.

Total metal concentrations in the overlying water were also positively correlated with suspended solids and shaking frequency at each site. Dissolved metal concentrations were also examined during experimental shaking. All metals positively correlate with time, except zinc, only when the pH is at or below 7.5. Zinc is positively correlated ($p < 0.05$) with time for all pH values. Dissolved metals appear to follow a time-dependent release from sediments which is then depressed as the pH rises above 7.5 units; metal partitioning to sediment is observed as pH increases. Similarly, metal desorption increases (dissolved metal concentrations increase) as pH decreases and may have implications concerning toxicity. The inverse correlation of dissolved metals with pH is suggestive of surface adsorption controls on solution concentration. Results indicated that zinc and nickel were relatively more mobile than lead and cadmium. As well, metal speciation, i.e., for chromium, may play an influential role due to a mixture of oxidation state. Particular ionic forms would be expected to exhibit the inverse behavior with respect to pH on solution concentration.

Typically, pH of the overlying medium significantly ($p < 0.05$) increased with shaking time. The influential factors resulting in the pH increase are unknown but may be related to CO₂ release from the sediment column during shaking; other factors are also probably synergistically involved. Because sediment cores vary with depth and are not homogenous vertically, shaker action may introduce areas of different acidity regimes. The range of pH observed during experimentation was 7.0-8.6 pH units which falls within the historical pH of the Detroit River.

A surprising feature from experimentation was the lack of a significant correlation between respective dissolved and total metal concentrations. Although the influential factors are unknown, several dissolved metals correlate inversely with frequency and suspended solids, as opposed to total metal relationships. This observation may be related to the rate that equilibrium is approached. If metal release from sediment particles is entirely or partially limited by mass transfer, release may be expected to be greater at higher particle velocities where boundary level effects are less pronounced.

Further discussion may be found in DePinto et al. (1987), Appendix A, and Lick et al. (1987), Appendix G.

SEDIMENT AGGREGATION/DISAGGREGATION STUDIES

The effects of shear stress and suspended solids concentrations on particle flocculation were investigated and two primary relationships were observed. Results indicated that steady-state median floc diameter decreased from 115 to 50 μm as shear stress increased from 1 to 4 dynes/cm^2 at a suspended solids concentration of 100 mg/L; a similar relationship was also recorded for a concentration of 400 mg/L. Microscopic examination indicated that flocs formed at lower shears were more loculate and fragile than those formed at higher shears; effective densities were also lower at lower shears. When a constant shear stress of 2 dynes/cm^2 were applied to intervals of solids concentrations of 50 to 800 mg/L, steady-state, median floc diameters decreased at corresponding sizes ranging from 100 to 26 μm . These relationships clearly show the effects of shear stress and concentration on the flocculation/de-flocculation process. Additional

experimentation indicated that floc size was dependent on shear stress regardless of previously applied shears. When an initial shear was applied followed by a different shear velocity, floc size would attain a diameter related to the second shear stress. The aggregation and disaggregation of flocs may have a significant impact on the transport and deposition of contaminants because of surface area and the effects on settling speeds of particles and have been accounted for in numerical models describing the sediment transport process.

For further discussion, refer to Lick et al. (1987), Appendix G.

BIOLOGICAL TOXICITY AND MUTAGENICITY

Bacteria

Based on luminescence inhibition of Photobacterium phosphoreum by sediment porewater, Microtox[®] results indicated that the western, nearshore zone of the Trenton Channel had the greatest number of very toxic sites in the study area. Stations 30UP, 112, 34, 30CR, 25, 45, 106, and 30, respectively, were the most toxic observed. All of these stations induced a 50% (EC50) reduction in bioluminescence with less than 100% concentration of porewater. Porewater from a large number of other stations elicited moderate and weak toxic responses. Thirty percent of the stations tested were non-toxic.

In addition to the 30 primary IPP stations, 106 other stations were assayed using the Microtox[®] technique. The sampling array for this more extensive study included stations in and as far north as the Rouge River and extended southward to Lake Erie on both the east and west sides of Grosse Ile. Of the 136 stations assayed, 25 were very toxic, 60 moderately toxic,

10 slightly toxic, and 41 non-toxic. A few very toxic stations were observed in the Rouge River and at several isolated localities throughout the study area; however, the greatest number and the most severely toxic were observed in the Trenton Channel, reinforcing the toxicity pattern observed in the primary IPP stations. Results indicated that large expanses of the lower Detroit River, primarily north and to the east of Grosse Ile, were non-toxic or slightly toxic. For further discussion of the Microtox[®] bioassay refer to Giesy et al. (1987a), Appendix I, and Giesy et al. (1987b), Appendix J.

Native bacterial biomass in the water column was highest (mean: 4.1 million cells/mL) at Station 53 and lowest at Station 30CR (3.1 million cells/mL). The largest range of bacterial abundance and a peak of 12.1 million cells/mL were observed in October, however, May and June samples generally showed the greatest abundance. Uptake corrected for biomass was highest in October and lower during the springs months. Greatest average uptake was highest at Station 53 (15.5 $\mu\text{g}/\text{million cells/mL/hr}$) and lowest at Station 34 (10.9 $\mu\text{g}/\text{million cells/mL/hr}$).

Uptake rates of native bacteria were inhibited when increasing concentrations of control and contaminated sediment were introduced to test populations. Uptake was suppressed in both control and contaminated experiments over a range of 12 to 1200 mg/L sediment concentrations. However, at 120 mg/L sediment concentrations, control sediment inhibited uptake by 50% whereas sediment from the Trenton Channel, at the same concentration, reduced uptake by 75%. These results demonstrate both sediment concentration and sediment toxicity effects. Elutriate also exhibited a increased inhibition, relative to increased concentrations used

to prepare the elutriate. No inhibition of bacterial uptake was observed for toxicity tests using porewater. Additional discussion of bacterial uptake can be found in White et al. (1987a), Appendix K.

As determined from the Ames Test, using the bacterium Salmonella/microsome assay, some degree of mutagenicity potential was observed in sediment for 92% (28/30) of Detroit River stations. No distinct areal pattern was observed, although most of the strongly mutagenic sediment was from directly in the Trenton Channel. Moderately mutagenic sediment was observed throughout the entire study area, but many of these stations were concentrated in the lower reaches of the river near Lake Erie. Within the group of sediments exhibiting a potential for mutagenic effects, six were mutagenic without (-S9) metabolic activation, those included 30UP, 34, 51, 54, 111, and 112. No mutagenic potential was detected at Station 83 - Fighting Island (reference station) nor at Station 52 - Hickory Island, outside and west of the Trenton Channel and its flow. See Maccubbin (1987), Appendix Q, for further discussion of the Ames Test.

Phytoplankton

Ambient chlorophyll a concentrations were somewhat bimodal in the Trenton Channel. Concentrations were highest in May and June (2.3 $\mu\text{g/L}$), lowest in August (0.7 $\mu\text{g/L}$), and moderate in October (1.3 $\mu\text{g/L}$). In general, Station 30CR had the highest mean concentration for the season. Algal uptake decreased from a high in the spring to a low in the fall.

Phytoplankton uptake, upon exposure to sediment, appeared to exhibit the same trends as noted for bacteria but more pronounced. Typically, the addition of sediment (whether clean or contaminated) inhibited photosynthetic

activity and uptake; greater sediment concentrations suppressed uptake for both sediment types. This observation is reasonably attributed to water transparency and its relationship with light availability. At 120 mg/L uptake was reduced by 40% for the control sediment and 56% for contaminated sediment and a 90% reduction for control and 93% for contaminated sediment at 1200 mg/L sediment concentration; again suggesting a large inhibition by sediment and a lesser potential inhibition by toxic substances. Elutriate assays followed the same pattern where greater inhibition was observed with higher sediment concentrations used to prepare the elutriate solution. Porewater showed no toxic effect on phytoplankton uptake. Analysis of variance indicated that the most pronounced effects were observed during the spring months.

Refer to White et al. (1987a), Appendix K, for additional information concerning phytoplankton uptake.

Zooplankton

Of the 30 stations examined, no lethality of D. magna was observed at 20 stations upon exposure to sediment porewaters. Of the 10 stations inducing Daphnia mortality, Station 30 was relatively the most toxic. The next most toxic porewaters were from Stations 30UP, 112, 34, 30CR, and 107. A 50% mortality (LC50) was observed for eight of the stations after a 96-hour exposure to 50% or less porewater concentration. Most stations producing Daphnia mortality were centered in the Monguagon Creek area and southward. Refer to Giesy et al. (1987b), Appendix J, for further discussion.

Zooplankton-phytoplankton interactions were examined upon exposure to contaminated sediment by determining Daphnia ingestion rates on Cryptomonas.

Greatest feeding inhibition was typically observed at highest elutriate concentrations. Typically, 50-70% elutriate induced the greatest feeding inhibition. Of the four sites investigated, sediment elutriate from Monguagon Creek elicited the greatest reduction in ingestion rate; approximately a three-fold decrease. Black Lagoon, Station 34, induced a two-fold feeding reduction. Fighting Island (reference Station 83) and Gibraltar Bay, Station 53, showed slight feeding suppression at the high elutriate dilutions. An account of zooplankton-phytoplankton feeding can be found in White et al. (1987a), Appendix K.

Samples from the lower water column of the Detroit River significantly ($p < 0.05$) reduced the reproductive success (mean young produced/female) of Ceriodaphnia during most times of the year, relative to a Lake Michigan control. All four stations investigated, Monguagon Creek (30CR), Gibraltar Bay (53), Black Lagoon (34), and Fighting Island (83-reference) exhibited some degree of reproductive inhibition during a six month period. Station 83 (Fighting Island) exhibited significantly ($p < 0.01$) decreased reproductive success during all surveys and was the most toxic (in terms of low number of young produced/female and percent survival) station assayed. Generally, mean young produced per female at Station 83 was 30% or less (down to 0 produced) than the number produced using control station water. Black Lagoon, Gibraltar Bay, and Monguagon Creek, respectively, induced severe reproductive impairment. Although trends were variable with season, general inhibition patterns were fairly constant as to relative toxicity. All four stations generally exhibited greatest reproductive impairment during the summer months

from July through September. Ceriodaphnia chronic bioassay is discussed further in White et al. (1987a), Appendix K, and Appendix L.

Oligochaetes

Densities of macrozoobenthos in sediments at Stations 30CR and 53 were very low; no living macroinvertebrates were observed at Station 34. Sediment from Station 30CR contained Tubifex tubifex, Limnodrilus hoffmeisteri, and two species of chironomids; densities of worms and midge larvae were less than 200 per m². Sediments from Station 53 had higher densities of tubificids (to 1000 per m²) but no other macroinvertebrates were present. The reference site (Station 83) contained a more normal diversity and density of macrozoobenthos. Limnodrilus spp., Tubifex tubifex, Quistadrilus sp., a variety of chironomids, Hexagenia sp., and Sphaerium sp. were observed.

The oligochaete, Stylodrilus heringianus, exhibited a sediment avoidance response to all sediments tested, relative to control sediment. When introduced to control sediment, all worms burrowed within one hour, and remained buried over a 48-hour period with no mortalities; fecal mounds were present after six hours. Burial results for Stations 53 and 83 sediments were similar. For both stations, about 70% of the worms remained buried after a 48-hour period with 5-8% mortality. However for Station 30 sediments, only 50% remained buried and a 12% mortality occurred. The response at Station 34 was very dramatic; only 10% of the specimens remained buried after 48 hours and a 53% mortality was observed.

Refer to White et al. (1987a), Appendix K, and White and Keilty (1987), Appendix M, for discussion of macrozoobenthos.

Insect Larvae

Chironomus tentans growth bioassay indicated that bulk sediment from the western, nearshore area of the Trenton Channel inhibited growth to the greatest extent, relative to the control. Stations 34, 107, 105, and 104 were the most growth-inhibitive for C. tentans; growth rates were 0.02 to 0.03 mg/d for these stations and growth was inhibited by greater than 90%, relative to the control. Growth rates were as high as 0.53 mg/d. The reference station (83) exhibited a growth rate of 0.48 mg/d and three stations showed slightly greater growth to a maximum of 0.53 mg/d. The Chironomus tentans chronic growth assay is discussed in Giesy et al. (1987b), Appendix J.

Chironomus tentans was employed in an avoidance response assay. In all cases, Stations 30, 34, 53 and 83 showed very large and many times significant differences ($p < 0.05$) in C. tentans escape response, respiration, and rest. Escape time (turning and crawling) was usually significantly higher ($p < 0.05$) at all four stations relative to the control. Similarly respiration and rest were lower (many significantly ($p < 0.05$)) in test sites compared to the control. Although an avoidance response was observed at all stations, respiration was not extremely low, and in a very toxic environment, the rest period may decrease to zero. See White et al. (1987a), Appendix K, for a detailed discussion.

Fish

Studies of channel catfish indicated that sediment concentration affects fish feeding rates on Chironomus tentans. Generally, sediment from Station 34 inhibited feeding the greatest, although significant ($p < 0.05$)

differences were not observed. Sediments from other stations elicited approximately the same response in feeding rate. Porewater and water column assays did not show differences in inhibition among sites, nor different responses to varying concentrations of porewater. Some results may be affected by the tolerance of channel catfish to adverse conditions and conditions in these experiments may not have been severe enough to elicit distinct decreases in feeding rates. Further discussion can be found in White et al. (1987a), Appendix K.

All sediment extracts injected into rainbow trout embryos increased mortality relative to the solvent-carrier control. Generally, mortality was increased by 2 to 3-fold and was most pronounced in the early sac fry stage. Approximately 50-100 survivors are available for autopsy from each of the master stations. These experiments have just been completed. Preliminary results indicate that about 3% of fish surviving for a one-year, post-exposure exhibited liver neoplasms from Station 30CR extracts, 1.6% from Station 53, and 1.3% from Station 34. All specimens were exposed to sediment extracts at concentrations of 100 µg/egg. Examinations are presently continuing. Refer to Maccubbin (1987), Appendix Q, for further details.

LARVAL FISH PASSAGE STUDY: DETROIT RIVER

Thirteen species/taxa of larval fish were observed in the Detroit River during the passage study, those included: yellow perch, rainbow smelt, suckers (genus Catostomus), coregonines (probably bloater), burbot, darters (johnny darter and other Etheostoma), mottled sculpin, deepwater sculpin, white bass/white perch (Morone spp.), gizzard shad, walleye, and crappie.

Yellow perch, white bass/white perch, and rainbow smelt were the most abundant, respectively.

Distinct distributional patterns were observed both laterally and longitudinally for some larval species in the study area. Bloater, burbot, and deepwater sculpin exhibited greatest densities in the upper reaches of the Detroit River but were present throughout its length. These species were probably transported to the system from Lake Huron and possibly from Lake St. Clair. Conversely, yellow perch, white bass/white perch, rainbow smelt, and walleye larvae were in greatest densities in the lower sector of the River near the confluence of Lake Erie. Walleye and white bass/white perch were not observed in upper reaches of the River and yellow perch and rainbow smelt exhibited relatively low abundances. Densities of the larvae significantly ($p < 0.05$) increased in the mid-Trenton Channel area (transects 12-13) and then exhibited the greatest abundances downstream near Lake Erie (transects 16-17). The significantly ($p < 0.05$) greater densities of walleye, yellow perch, and white bass/white perch in the mid-Trenton Channel suggested a spawning ground and nursery in the vicinity. It is suspected that the shallow, vegetated areas at Mud and Grassy Islands, just north of the Channel, may provide a protected area for spawning and is the primary local source of larvae. The relatively greatest densities of walleye, yellow perch, and rainbow smelt observed in the confluence area were probably entrained from Lake Erie and transported to the lower River under the south wind regime that occurred during the study period. Results of the 24-hour larvae sampling at the Grosse Ile free-bridge indicated that there was a

consistent input of larval fish into the Trenton Channel. Although densities exhibited moderate variability, a substantial supply of larvae was indicated.

Yellow perch showed the strongest lateral distribution gradients of the taxa observed. Greatest larval densities were recorded in the western, nearshore area and decreased through the main channel, exhibiting lowest densities in the eastern sector. White bass/white perch and rainbow smelt did not exhibit a significant ($p < 0.05$) east-west gradation in densities. Length-frequency histograms indicated no east-west differentiation by size. However, the greatest abundances of 5.0-6.0 mm yellow perch larvae were recorded from the lower river and generally 8.0 mm larvae were observed in the Trenton Channel.

Investigations of zooplankton populations as potential larval food sources indicated that 85% of the zooplankton collected were copepods; cladocerans and rotifers, respectively, were considerably less abundant. Observed during the study were calanoid, cyclopoid, and nauplius copepod larvae, Bosmina, Limnocalanus, rotifers, and a host of other zooplankters at very low relative abundances. Except for rotifers, the above zooplankters exhibited significantly ($p < 0.05$) greater densities during night than during day. Concurrent with the diel pattern, abundances typically increased for all species during the study period but distribution was typically patchy. Ceriodaphnia bioassay results indicated that all Detroit River stations inhibited zooplankton reproduction to some degree. Greatest relative depression was observed in the upper reaches of the River and at the Lake Erie confluence; 40% survival was observed with the lowest average young per

female. Ninety percent survival was observed for two stations in the Trenton Channel as well as substantially greater young per female.

Physical-chemical measurements indicated lateral and longitudinal gradients. Chlorophyll a and pH decreased proceeding downstream and were generally highest near the eastern shoreline. Conversely, conductivity, ammonia, nitrate, chloride, hardness, and silica increased in a downstream direction and were generally higher on the western sector of the Channel.

Preliminary analyses of larval gut contents throughout the length of the River have been conducted. Stomach contents of larval yellow perch were similar from Lake St. Clair to just north of the Trenton Channel. Zooplankton increased by two-fold in stomach contents just north of the Trenton Channel then decreased slightly toward Lake Erie. Entrainment from the nursery area at Mud and Grassy Islands appeared to increase larval abundances and these larvae had greater numbers of zooplankton per stomach, relative to those observed to the north. Although further analyses are necessary, the nursery ground and the entrainment of actively feeding larvae from this site may confound comparisons between upper and lower reaches of the entire River.

One hundred and eleven yellow perch larvae were examined from collections made at the Grosse Ile free-bridge; specimens ranged in total length from 4.8 to 11.5 mm. Feeding incidence was typically low among larvae where only 23% had ingested zooplankton; zooplankters were the primary diet of all larvae observed. A lateral gradient was observed in food items ingested. For most size classes, greatest feeding was observed in the eastern nearshore zone and then decreased toward the main channel and the western nearshore area,

respectively. Results of the stomach analyses suggested that the degraded water quality in the western portion of the Trenton Channel decreased larval yellow perch feeding.

Analysis of gut contents, additional physical-chemical parameters, and heavy metal concentrations are underway. For further discussion, refer to White et al. (1987b), Appendix N, Flexner (1987), Appendix O, and Appendix P.

FISH TUMOR SURVEILLANCE AND INCIDENCE

Several neoplasms and pre-neoplastic lesions were observed in fish species in the Detroit River. Target species collected include brown bullhead, walleye, redhorse sucker, white sucker, and bowfin. Lesions can be classified by anatomical location: external (oral/dermal) and internal (liver). External neoplasia and associated lesions recorded were epidermal papillomas, neuroepitheliomas, epidermal hyperplasms, and fibromas. Tumorous or pretumorous conditions associated with the liver were determined by necropsies followed by histopathological examination. Several forms of neoplasms were recorded but eosinophilic foci, clear cell foci, and hepatocellular carcinomas were those observed most frequently. Incidence varied with species, fish size, and locality.

Of all fish examined from the Detroit River, dermal/oral tumor and liver tumor incidences were 10.0% and 9.4%, respectively. Bullhead and walleye were the only two species exhibiting dermal/oral neoplasms at 14.4 and 4.8%, respectively. Bullhead, walleye, and bowfin exhibited liver neoplasms; highest incidence was observed for bowfin at 15.4% (see Maccubbin et al., 1987, Appendix R). Bullhead and walleye exhibited incidences of between 8 and 10%. In bullhead, a relationship between dermal/oral and liver tumor

incidence was not apparent, suggesting different exposure mechanisms, i.e., direct contact versus exposure through food. Tumor incidence appeared to be an age-related phenomenon (size is assumed to be approximately indicative of age). No tumors were present in bullheads less than 25 cm in length and in walleye less than 50 cm. Greatest incidences were observed in bullhead greater than 30 cm and walleye greater than 50 cm.

Tumor incidence was also evaluated spatially in the River. Of the six sites intensively examined (all fish greater than 25 cm), bullheads at Station 77 - Hennepin Point and Station 53 - Upper Gibraltar Bay exhibited the greatest incidences of dermal/oral tumors at 36.4% and 33.3%, respectively. Greatest liver tumor incidence was also observed at Hennepin Point (21.1%) followed by Celeron Island (15.4%). Conversely, bullheads examined from Mud Island, north of the Trenton Channel, and Station 43, in the lower Trenton Channel, did not exhibit tumors. Only walleye (greater than 50 cm) from Hennepin Point and Grassy Island had tumors. Dermal/oral lesions in walleye were 14.3% at Hennepin Point and 11.1% at Grassy Island. Liver tumors in walleye were 28.6% and 22.2% at Hennepin Point and Grassy Island, respectively. The distribution patterns from final data will be somewhat spurious primarily due to fish availability; sites in the mid-sector of the Channel yielded no or very few fish and these sites are not available for evaluation.

Benzo(a)pyrene metabolites were sought in samples of fish bile. All target species had evidence of benzo(a)pyrene (BaP) exposure as determined from bile analyses. A particular species within and between sites generally exhibited a moderate degree of variability. Walleye and redhorse sucker

contained the greatest BaP concentrations; bullhead concentrations were substantially lower. Spatially, greatest BaP concentrations were observed in bowfin and redhorse sucker at Hennepin Point and in bullhead, walleye, and white sucker at Mud Island. Correlative analysis of influential factors in regard to tumor incidence has not been attempted at this time.

Maccubbin (1987), Appendix Q, and Maccubbin et al. (1987), Appendix R, should be referred to for more discussion of fish populations.

CONTAMINANTS IN YOUNG-OF-THE-YEAR DIVING DUCKS

Young-of-the-year diving ducks were collected by shotgun at Mud Island, Detroit River in 1981. Male and female specimens of three species were obtained: goldeneye, greater scaup, and lesser scaup. For all 15 specimens analyzed, total PCB concentrations ranged from 0.730 to 22.394 mg/kg. Although moderate variability was observed, highest concentrations were observed in males for all species. Similarly, variance within each species was considerable, however, goldeneye had the highest mean concentration followed by lesser scaups and greater scaups.

Raw data are presented in Appendix S.

CONTAMINANTS IN CONNECTING CHANNELS MACROPHYTES

Heavy metal concentrations were determined for seven macrophyte samples. Stations were unknown and the seven samples included one designated as a control. All seven metals were detected in all seven samples. Zinc exhibited the greatest relative concentrations in all samples (maximum 183.85 mg/kg). Copper and nickel exhibited high concentrations relative to lead, cadmium, cobalt, and mercury; mercury concentrations were several orders of

magnitude less than other metals. No co-occurrences of metal concentrations were observed on a station-by-station basis. Various samples had high concentrations of one metal and low of another. This observation also held for the control sample, however, the control macrophyte sample generally exhibited relatively low concentrations.

Hexachlorobenzene, octachlorostyrene, and total PCB analyses were conducted on 17 macrophyte samples. PCB was detected in four samples and ranged from 280.2 to 1592 ng/g; fourteen samples were below the detection limit. Two samples contained octachlorostyrene at concentrations of 0.33 and 0.62 ng/g; other samples were either below the detection limit for octachlorostyrene or not detected. Hexachlorobenzene was observed in all but one sample and ranged from 0.69 to 10.3 ng/g. Co-occurrence between organic contaminants was not observed nor between organic and heavy metal concentrations on a station-by-station basis.

Raw data for macrophyte sample analyses are presented in Appendix T.

MATHEMATICAL MODELING

The In-Place Pollutants project, in combination with the Detroit River System and Trenton Channel Microscale Mass Balance Projects, will allow various aspects of the sources, fate, transport, and biological effects of toxic substances to be expressed probabilistically and then evaluated. Components to be used in the modeling effort are: contaminant loadings, ambient concentrations of sediment and sediment porewaters, resuspension potential, sediment transport, and biological toxicity. Model results will provide a means for synthesizing and standardizing all results for comparative purposes and for use as input in subsequent modeling efforts.

The loading of point sources and resuspended sediments will be used in a probabilistic water quality, mass balance model to compute the probability distribution of toxic unit concentrations expected in the water column. Transport and associated processes will be determined to quantify the extent of exposure and effect. The possible chemical cause of toxicity is to be examined by relating the observed toxic unit concentration in the sediment, porewater, and/or overlying water to the properly normalized chemical concentrations.

Sediment resuspension potential and flux are being quantified using field instrumentation. Since the distribution of meteorological events is random and affects sediment resuspension, the probability distribution can be appropriately represented in a probabilistic model. Bioassays have been conducted for sediment, porewater, elutriates, and for the lower water column; dose-response curves have been determined for bioassays.

Transport will be addressed in the mass balance modeling efforts. The six-cell segmentation scheme employed for the River will allow calculations on a fairly small-scale basis. Components involved in the calculations are flow (velocity and volume), geometry, and conservative tracers. Tracers, i.e., temperature, specific conductance, dissolved oxygen, pH, alkalinity, and chloride are used to determine observed river structure in gradients and as model calibration parameters. Results define the longitudinal and lateral transport vectors. Preliminary results indicate that a more pronounced lateral rather than longitudinal gradient exists in the Detroit River. In this vein, lateral transport is minimal, promotes the gradient, and indicates that biological effects may be primarily restricted to longitudinal vectors.

The resuspension, transport, and bioassay results will be used to establish the relationship between concentrations of resuspended sediment and the resulting toxic unit concentrations to be expected during a transport event.

Given an areal mapping of contaminant concentrations and toxicity, the remaining question is the extent to which these areas represent an ecological hazard to the system as a whole. Scenarios are: little effect, short-term hazard, long-term hazard, restricted, or large scale effects. Modeling this process requires that toxicity be expressed in toxic units which are derived from bioassay dose-response curves. A toxic unit (TU) is a measure of concentration toxicity and is defined as the inverse of the concentration or dilution fraction in sediment, porewater, or overlying water which causes a 50% response in a given bioassay (i.e., EC50 or LC50). Thus:

$$TU = 1/EC50 \quad \text{Equation 1}$$

For example, if zooplankton reproduction is reduced by one-half at a 10% elutriate concentration, then the EC50 of that sample is 10% (or 0.1 dilution fraction) and the sample is assigned 10 toxic units. Bioassays have been conducted in a manner to provide dose-response functions for a range of exposure or toxicity concentrations. The dose-response characterization reduces results of all assays to a standard quantification of toxic units.

The dose-response functions may be assessed using slopes and intercepts and toxic units directly computed. A log-logistic model is employed to analyze and compare dose-response data generated for each bioassay:

$$R = R_0 / \{1 + e^{[\ln \phi - \ln \alpha] / \beta}\} \quad \text{Equation 2}$$

where:

R = response variable observed in the test

R_0 = response variable observed in the control

ϕ = dilution fraction of test matrix

α = dilution fraction at which $R_0 = R/2$ (EC50 or LC50)

β = measure of test population sensitivity

The parameter, β , defines the response as to whether the toxicity is gradual or abrupt as the fraction of test water increases (the lower the β , the more abrupt the response).

The dose-response function is fit to the data using a non-linear least squares fitting computation that determines the optimal values of R_0 , α , and β for each station. A single value of the parameters, R_0 and β , is determined for all stations within a survey because these are characteristic of the test population which is the same for all of the tests conducted for a survey. The α values are determined separately for each station reflecting the variation in the concentration of toxicants from station to station. The EC50 (α values) determined for each station is converted to toxic units as previously cited.

A wide array of bioassays have been conducted in the Trenton Channel. The multiplicity of assays on each of the components of the sediment-water system allows a comprehensive evaluation of the extent and possible causes of toxicity at each station to different trophic levels. Causal relationships are determined through the intercomparison of toxic unit concentrations, the correlation of toxic unit concentrations to chemical concentrations, and the direct modeling of toxicity as a water quality variable.

The probabilistic modeling aspect of this study will address the question of whether sediments from particular localities should be remediated, for example, by dredging. The predictive capability will allow a determination to be made of whether biological impacts and effects are local or whether effects are predicted or observed at sites downstream from sediment resuspension and transport. In this way, sites which pose a potential hazard to other areas of the ecosystem can be identified.

For a further discussion of modeling, refer to Di Toro et al. (1987), Appendix U.

PILOT APPLICATION OF THE SEDIMENT ACTION INDEX

The Sediment Action Index developed is a simple ranking system which utilizes a series of chemical, biological, and physical measurements to numerically rank sites relative to their degree of degradation and/or potential hazard to the ecosystem. The system reduces and synthesizes a considerable amount of data so that the data base can be used for regulatory and remedial decisions. Results of the system indicate the most severely degraded or impacted sites/areas and are presented in a prioritized manner. The sites identified are those which should most-likely receive consideration for either further study or direct remedial and regulatory actions. The multidisciplinary data base generated in this study of the Trenton Channel provides an opportunity to apply the concept of the Sediment Action Index. Although the pilot application of the ranking system uses a data base from a specific study area, the concept of this system is anticipated to be applicable to comparisons within and among specific regions, Areas of

Concern, lakes, watersheds, areas within specific state jurisdictions, coastal zones and estuaries, or to the waterways of the nation.

Development of the system will be phased and extend from simple to more complex iterations; a preliminary, simple iteration is presented here. Various aspects to be explored during development of this system include: different ranking and mechanical techniques, combinations of variables, discrimination techniques, weighting techniques for specific variables, derivation of new variables from the data base, and sorting of redundant information. The system has been computerized because of the large data base used, the requirement to inspect different techniques, and the computer-intensive needs associated with these factors.

The system is an M by N matrix of physical, chemical, and biological variables by site. Generic and individual variables form columns and stations (station number) form the rows of the matrix. Eight generic variables were used in this iteration and include: heavy metal concentrations in bulk sediment, heavy metal concentrations in sediment porewaters, sediment concentrations of total PAHs, total PCBs, hexachlorobenzene, and total organic carbon; toxicity and Ames Test mutagenicity. Individual variables were sediment and porewater concentrations of zinc, cobalt, cadmium, lead, copper, chromium, and nickel; Daphnia magna (LC10 and LC50), Microtox[®] (EC10 and EC50), and Chironomus tentans growth reduction. For this pilot iteration, three generic variables (heavy metals in sediment, heavy metals in porewater, and toxicity) have been derived from combining individual variables so that each generic variable has equal weightings for ranking; in this iteration, organic contaminants have been slightly weighted where total

PCBs, HCB, and PAHs are treated as generic, rather than individual variables. Over 1000 data points have been included in this first application of the system.

For each individual variable (column) data points were ranked by station relative to the range of observations for that variable. Ranks ranged from 1 to 30 commensurate with the number of stations. In the case of a tie, the high rank was assigned. For example, if two sediment samples had a concentration of 500 mg/kg zinc and were tied for the 12th rank, each was assigned a rank of twelve. In the case of toxicity, when no toxic response was observed, that station was assigned a rank of 30. The sum of the ranks for each station (row) for each individual variable were calculated for a given generic variable (i.e., each heavy metal rank for all heavy metals) and were re-ranked for the generic variable by station. The sum of the ranks for each station (row) for all generic variables were calculated and then re-ranked. In both cases above, it was necessary to account for some missing data points by obtaining a mean subrank so that missing data did not influence the outcome. This entire procedure produces a relative rank for each station reflective of all variables available.

Results of the ranking indicated that the eight most severely degraded stations lie in the western nearshore zone of the Trenton Channel. These stations were confined to a 4-km zone from just north of Monguagon Creek, southward to Elizabeth Park. These stations encompassed eight of the nine total stations examined in this zone during the study. Stations included in this zone are 112, 110, 30CR, 105, 107, 34, 30, and 30UP, respectively. Stations outside of this zone were not encountered in the ranking until

position or rank number 9. Delineation of this zone was based on numerical as well as geographical considerations.

A second set of six stations were identified as the next most degraded (Stations 111, 43, 42, 25 44A, and 104). Station locations varied from the northeast Trenton Channel, to the mid-Channel, to the lower Channel; all were still in the Trenton Channel proper. The remainder of the stations were relatively less degraded than those cited above and had a wide distribution. In general, the degree of degradation decreased from the mid-Trenton Channel toward the north and south. As well, there was a distinct east-west differentiation in degradation in the mid-Trenton Channel. The nearshore zone on the eastern side of the Channel (Grosse Ile) was considerably less impacted than the western, nearshore zone of the Channel.

From inspection of the mean subranks (or sums) an initial discrimination of degradation severity can also be observed within the western, nearshore zone of the Channel. Stations 112, 110, and 30CR were moderately-well separated from one another, however, the next two sets of three stations had fairly similar sums. If a specific site was to be targeted for remedial action probably Station 112 would be a likely choice because of its relatively great degradation and potential impact on adjacent and downstream areas. On the other hand, the entire western region of the Trenton Channel is severely impacted and should be a likely choice for further study and/or remedial action. That is not to say that there is no concern for other sites and zones in the study area, however, action at these areas may be influenced by the remedial goals to be pursued. A degree of confidence can be stated for the recommendations made. For the stations outside of this impacted

region, only 21 out of 176 possible ranking positions (12%), were assigned ranks of 1 to 8, inclusive. This indicates that a considerable number of the most toxic, contaminated, and mutagenic sites in the study area were accounted for.

SUMMARY AND DISCUSSION

The Detroit River is the terminal waterway connecting the upper and lower Laurentian Great Lakes. Its multi-use waters are a critical element of the economy and well-being of basin residents in the State of Michigan and Province of Ontario. Noticeable progress in restoring this vital natural resource has been accomplished during the past decade. Most obvious is the removal of the gross symptoms and impacts of man's activities and wastes. However, the Detroit River remains an International Joint Commission "Area of Concern" and its beneficial uses are impaired (IJC, 1985). Recent studies of the Detroit River have demonstrated that the water column (Chau et al., 1985; Comba and Kaiser, 1985; Kaiser et al., 1985; Maguire et al., 1985; Platford et al., 1985) and sediments (Fallon and Horvath, 1985; Hamdy and Post, 1985; Kaiser et al., 1985; Maguire et al., 1985; Platford et al., 1985; Prankevicius, 1987) are contaminated with an array of anthropogenic substances. Apparently due to the array of contaminants found in the ecosystem, biota have exhibited symptoms of impact. Water samples have been shown to be toxic to bacteria (Ribo et al., 1985) and sediments to ultraplankton (Munawar et al., 1985). Macrozoobenthos communities in certain areas of the River are primarily composed of pollution tolerant populations (Thornley, 1985). A variety of contaminants have been shown to be bioavailable to and present in, the tissues of many levels of the trophic spectrum: insects (Ciborowski et al., 1988), clams (Kauss and Hamdy, 1985;

Pugsley et al., 1985), ducks (Smith et al., 1985). The subject of this investigation, in-place sediment pollutants, is focused on only one, of the suite of nine major environmental problems cited by the International Joint Commission, which exist in the Detroit River.

Evidence from the present study indicates that sediments in many areas of the Trenton Channel are highly contaminated with a complex mixture of heavy metals and organic compounds. Sediment, sediment porewater, sediment elutriate, and/or water samples from all 30 primary IPP stations investigated, elicited a toxic and/or mutagenic response in at least one bioassay, in the suite of assays employed for this investigation. Toxicity to various representatives of the trophic spectrum which included bacteria, phytoplankton, zooplankton, oligochaetes, insects, and fish, was demonstrated. Bioassays indicated that reproduction, growth, metabolism, behavior, survival, and feeding of biota were impaired by sediment, sediment porewater, sediment elutriate, and/or water samples from the Trenton Channel. Based on contaminant concentrations and toxicity tests, a numerical ranking system indicated that the most severely degraded stations in the study area were concentrated in the western nearshore zone of the Trenton Channel. This region extended for 4 km from the Monguagon Creek area to Elizabeth Park. Stations within this region also exhibited a relatively potential for sediment resuspension which could ultimately have impacts on the water column and adjacent and downstream sites.

Other biological investigations revealed information concerning the health of the Detroit River ecosystem. A limited survey of benthic communities showed a wide range of Detroit River macrozoobenthic populations

from pollution-tolerant to desirable, pollution-sensitive species; community structure appeared to be associated with contaminant gradients. However, one site was devoid of benthic populations. A continuous supply of larval yellow perch to the Trenton Channel was observed; however, those obtained from the western sector of the Trenton Channel appeared to have ingested relatively less food than those from other portions of the Channel. A wide variety of fish species were observed in the Detroit River during surveillance operations. Fish tumor incidence in the River was approximately 10% and lesions were primarily detected in bullhead and walleye; both external and internal neoplasia was observed. Young-of-the-year diving ducks exhibited relatively high PCB concentrations in flesh, compared to values typically observed in Great Lakes fish. Sex and species of the ducks appeared to show an association with the relative PCB concentration observed in tissue.

For summary and discussion purposes in the following, results from certain study components and tasks will be presented for the study area as a whole. A subsequent discussion of the salient features and findings from particular zones in the study area, will then be presented.

All eight heavy metals sought in this study (zinc, lead, copper, nickel, chromium, cobalt, cadmium, and mercury) were detected at all sites in bulk sediment; zinc, lead, and copper were observed in greatest relative concentrations. Highest concentrations of all metals were observed in the northwestern sector of the study area. Heavy metals strongly co-occurred correlated, in terms of concentrations, throughout the study area. All metals correlated with total organic carbon and loss on ignition. Twenty-two of the 30 primary IPP stations exceeded USEPA guidelines for heavily polluted

sediment for at least one metal. Heavy metal concentrations in porewater did not correlate with those in sediment. In porewater samples, zinc, copper, cadmium, and nickel were usually in greatest concentrations, as opposed to bulk sediments; cobalt was not detected in some porewater samples. Apparently, metal concentrations in bulk sediments do not solely control concentrations observed in porewater.

Results of shear-stress simulations using a shaker apparatus, where sediment oscillation was controlled, indicated that sediment concentrations increased rapidly in overlying water during the first five minutes and steady-state was achieved after ten minutes. It has been shown that the amount of cohesive sediments which can be resuspended by applied shear stress is finite (MacIntyre et al., 1986). From previous studies, it has been demonstrated that steady-state concentrations obtained in shaker experimentation is a reasonable estimate of that amount (Tsai and Lick, 1986). The experimentation indicated that the amount of sediment suspended for certain stations (34, 53, and 30) was higher under the same shear than others (46, 53A, 42). Results indicated that the stations with the greatest resuspension potential were usually the most severely contaminated. Those with higher resuspension potentials also had finer-grained sediment than those with lower potentials. Characterization of the overlying water after shear-stress simulation indicated that dissolved metals may follow a time-dependent release which is depressed as the pH rises above 7.5 pH units. Also, dissolved metal concentrations did not correlate with initial, total metal concentrations; the influential characters are unknown.

Flocculation has a significant effect on the effective sizes, surface areas, densities, and settling velocities of fine-grained particles. Experimental results employing an annular flume indicated that steady-state, median floc diameter decreases as shear stress increases at a constant suspended solids concentration. However, at a constant frequency, floc diameter decreases as solids concentrations increases. Dynamic flocculation of particles and associated properties have a considerable influence on sediment transport, fate, and deposition. When flocculated at particular solids concentrations, sediment may be transported for greater distances, extending the range of redeposition and biota exposure to associated toxicants.

Results of transport modeling using resuspension, deposition, and flocculation measurements as inputs, indicated that very little lateral displacement or mixing occurs in the lower Detroit River. The longitudinal flow of the River largely dominates transport and restricts lateral transport. These results are reflective of physico-chemical and contaminant gradients observed in the River.

Polychlorinated naphthalenes, polychlorinated terphenyls, and polycyclic aromatic hydrocarbons (PAHs) were detected in sediments from the Detroit River - Trenton Channel study area. Greatest concentrations were observed in the northwestern sector of the study area. Distribution patterns ranged from restricted to the Trenton Channel (polychlorinated terphenyls) to pervasive throughout the study area (PAHs).

Many PAH concentrations observed in the study area are indicative of highly contaminated sediments. Sediment samples from remote sites typically

contain PAH concentrations of less than 10,000 ng/g dry weight (Furlong et al., 1987b). Some sites in the Trenton Channel exhibited concentrations a full order of magnitude greater (133,000 ng/g dry weight). Concentrations observed in the present study compare reasonably well to concentrations calculated for six Trenton Channel stations from the data of Fallon and Horvath (1983, 1985).

Some of the greatest total PAH concentrations are located in the vicinity of suspected industrial sources. However, the interpretation of PAH distributions are not explainable at the present, and distributions may be confounded by factors other than source. Ratios of individual, photo-reactive PAHs, indicated that combustion-derived, atmospheric sources may not be a substantial contributor to the lower Detroit River and, at this point, can be eliminated from consideration. Uniformity in relative proportions of individual PAHs suggests that total PAH may be derived from a single source, from multiple sources that are not substantially different, and/or indicates that individual PAHs are well mixed prior to sedimentary deposition. Transport of sediments from the Trenton Channel suggests a considerable PAH load to the western basin of Lake Erie. The large PAH concentrations observed indicates active inputs and deposition in the Trenton Channel.

Concentrations of polychlorinated biphenyls were generally low, relative to concentrations observed in other areas of the Great Lakes. Concentrations in sediment ranged from 0.01 to 2.83 mg/kg. No distinct distributional pattern was observed with relatively high PCB concentrations found at various sites throughout the study area. Results of this and other studies of

contaminants in the Detroit River indicate that there are at least 200 contaminants present in this system (Pranckevicius, 1987; Fallon and Horvath, 1985, 1983; Hamdy and Post, 1985).

A suite of bioassays was applied to the Trenton Channel environment to determine areas of toxicity. Biological test organisms used spanned the entire trophic spectrum from bacteria to fish. This range of test specimens was used because certain trophic levels may respond differently to the complex mixture of toxicants observed in the Trenton Channel; furthermore, these bioassays were applied to determine which levels are the most sensitive to extant conditions. Primary and secondary ecosystem functions were used as response endpoints, including: metabolism, reproduction, feeding, growth, survival, and behavior.

Sediment, sediment porewater, sediment elutriate and/or water toxicity were exhibited at all 30 IPP stations investigated to one or more of the bioassays employed in the study. Microtox[®], Chironomus tentans growth and avoidance, Daphnia feeding, and Stylodrilus avoidance bioassays generally indicated that greatest toxic responses were observed in the Monguagon Creek region and southward. Numerous other inhibitory or toxic responses were observed at other stations but were less than those cited above. Based on results of the Ames Test, all but two stations exhibited a mutagenic potential. Stations with strong mutagenic potential were generally concentrated in the Trenton Channel proper.

Bacterial and phytoplankton uptake results exhibited the same general trends as above. Uptake of both organisms substantially decreased upon exposure to relatively uncontaminated sediment; uptake inhibition increased

as concentrations increased. Logically, the photosynthetic process of phytoplankton is inhibited by shading and turbidity. Generally, the addition of contaminated sediment decreased uptake further, but by relatively little, compared to the effects of turbidity. Bacterial and phytoplankton uptake were not affected by porewater. Bioassays of the lower water column using Ceriodaphnia suggested several points. All water column samples from the Trenton Channel reduced the reproductive success of the test specimen. Greatest reduction was generally observed during the summer months. This assay also indicated severe water column toxicity, compared to the other three stations intensively investigated, at Station 83 (Fighting Island reference station). From these results, the relative toxicity of water at Station 83 suggested a de-coupling of responses seen in the water column versus those in the bulk sediment/porewater.

Station 83 was selected as a reference station because it contained pollution-intolerant populations of Hexagenia limbata and Chironomus tentans, was north of some major industrial areas, and was outside of the Trenton Channel proper. Preliminary results indicated that it was a good choice as a reference site because little or no toxicity was observed to Microtox[®] and Chironomus tentans growth assays. In general, some toxic responses (and mutagenic response - Ames Test) were subsequently observed for Station 83 using the Chironomus tentans avoidance, Daphnia feeding, and Stylodrilus avoidance bioassays; however, these were fairly weak toxic responses. Several assays were conducted using a Lake Michigan control sample and, generally, the Fighting Island station showed less growth, feeding, etc., than the Lake Michigan control. Results of the Ceriodaphnia assay on the

lower water column was considerably accentuated at Station 83 compared to the other IPP stations and the Lake Michigan control. The assay indicated that a property in the water column induced a greater inhibition than what would be expected base on sediment assays. Despite the somewhat contradictory evidence from above, it appears that the site from Fighting Island is a good sediment reference station and is indicative of a relatively uncontaminated site in the Detroit River.

The relative sensitivity of three bioassays were evaluated, thus far, in this study: Microtox[®], Chironomus tentans growth and Daphnia magna lethality. Only 10 stations induced a toxic response by Daphnia magna. Compared to Microtox[®] and Chironomus tentans, the Daphnia magna bioassay was the least discriminatory of the assays and exhibited the fewest number of significant responses. The Daphnia magna assays may be partially inferred as being less sensitive but the test is based on the induction or absence of lethality and has no resolution or discrimination capability. Correlations among the assays showed the Chironomus tentans had exhibited the greatest resolution and discrimination among stations assayed. Microtox[®] was slightly less discriminatory than Chironomus tentans. It appears that certain tests, in this case, Chironomus tentans, show a greater capacity to discriminate and resolve conditions over the ranges of complex-mixture concentrations present in the study area.

The influences of Lake Huron/Lake St. Clair and of Lake Erie were observed in the distribution and densities of larval fish in the Detroit River. Distributions indicated that entrainment and transport to the Trenton Channel were active from both the north and south. Yellow perch, white

bass/white perch, and rainbow smelt exhibited the highest densities observed and were most prevalent (along with walleye) in the vicinity of Lake Erie; lower abundances occurred in the mid-Trenton Channel. However, the sizeable larval fish densities in the mid-Trenton Channel may be attributed to spawning and nursery areas in the vicinity of Mud and Grassy Islands, just north of the Channel. Based on a 24-hour sampling in the Trenton Channel, there appeared to be a fairly consistent input of entrained larvae to and transport through the Channel. From the diel patterns observed, entrainment and transport of Lake Huron/Lake St. Clair zooplankton populations through the River system was also evident. Zooplankton distribution, however, was typically patchy.

Greatest larval densities (particularly yellow perch) were observed in the western sector of the Trenton Channel. This longshore segment has the highest heavy metal and organic compound contamination in the sediment in the study area. However, Ceriodaphnia bioassay results from lower water column samples, indicated that relative to upstream and downstream areas, the Trenton Channel depressed zooplankton survival and reproduction rates the least; all Detroit River stations inhibited zooplankton reproduction and induced mortality to some degree, relative to the control. Preliminary analyses of stomach contents revealed that yellow perch larvae in the western nearshore zone of the Trenton Channel had ingested relatively less quantities of food, compared to those collected from the main and eastern portions of the Channel.

Fish tumor incidence was greatest at the extreme north and south ends of the Trenton Channel at Hennepin Point and Gibraltar Bay. This observation is

influenced by the availability of fish at these sites. Areas in the mid-portion of the Trenton Channel were reconnoitered for fish populations and were found to be very sparse. This could be construed as a direct effect of toxic contamination on fish populations. Although toxicity may be a factor, other factors such as bottom type, food source, river velocity, cover, proper vegetation, etc., are undoubtedly factors that affect fish distribution.

A considerable number of neoplastic lesions were observed in Detroit River fish. Neoplasia was not limited to bottom feeding fish but were also evident in a predator species. Neoplasms observed in the target species from the Detroit River have been previously reported for these species and were similar in type, to those described in other studies of fish populations in the Great Lakes system (Black, 1983; Grizzle et al., 1984). Liver neoplasia in bowfin and dermal fibroma in walleye from the Detroit River were the first such reports. The incidence of tumors in Detroit River fish was similar, and in many cases, lower than that reported for other industrially-impacted Great Lakes waterways such as the Buffalo, Fox, and Black Rivers (Black et al., 1982; Brown et al., 1973; Baumann et al., 1982). Some tumors have been observed in other fish species from other areas but were not observed in fish from the Detroit River. Larger-sized fish (>25 cm for bullhead; >50 cm for walleye) had distinctly greater neoplastic incidence than did smaller fish. Although size is only an initial indicator of age, it is assumed that incidence is age-related in the Detroit River, as observed in other studies (Baumann et al., 1982; Black et al., 1982).

The numerical ranking system (Sediment Action Index) developed during this investigation was designed to aid managers in setting priorities for remedial and regulatory actions. Admittedly, the system is only one element in a comprehensive remedial strategy and will require further development, identification and addition of the most appropriate variables, and the omission of redundant variables. However, the system appears to be intuitively sound based on inspection of the data, has considerable flexibility, and has potential for much broader applications. Advantages of the system are simplicity, ability to reduce large data sets for ease of interpretation, and ability to accommodate a wide array of unrelated parameters. A primary feature of the system is that it strictly utilizes numerical procedures and ranks sites objectively. Although this pilot iteration ranks sites within a particular study area, much broader geographical areas can be accommodated, i.e., a basin-wide ranking of Great Lakes harbors.

Ranking and classification is routinely conducted using descriptive statistics and/or subjective interpretation of the data base, e.g., the highest and lowest, the largest or smallest, the best or the worst, etc. In an environmental setting, the ranking of Superfund sites, hazardous waste sites within a particular state jurisdiction, and industrial effluents have been initiated and is the general intent of the Sediment Action Index. The Sediment Action Index also appears to be related to efforts and approaches being explored for establishing sediment quality criteria (Pavlou and Weston, 1983, 1984; Samoloff et al., 1983; Long and Chapman, 1985; Battelle, 1986; Chapman, 1986; Tetra Tech, 1986; Chapman et al., 1987a, 1987b). However, the

Sediment Action Index is strictly numerical ranking, utilizes a whole-effluent, toxicity-based approach, and is non-chemical specific.

Results of the Sediment Action Index identified four numerically-defined sets of stations, ranging from the relatively most-severely degraded to the least degraded. . Approximately 1000 data points were used in the iteration and included factors such as heavy metal concentrations in sediment and sediment porewaters, organic contaminant concentrations in sediment, three sediment toxicity tests, and mutagenic potential of the sediment. Of the four sets of stations identified, only the most severely degraded was geographically contiguous. This set encompassed the upper two-thirds of the western nearshore zone of the Trenton Channel; a gradient of degradation was also numerically determined within this region but was not composed of adjacent stations.

Those stations identified as highly degraded were located just to the southwest of Hennepin Point in the Trenton Channel and in the lower western Trenton Channel. Stations ranked as having moderate or low degradation were distinctly observed to the north of the Trenton Channel and at extreme southern sector of the study area in both the east and west nearshore zones. In general, as one proceeds away from the western nearshore zone of the Trenton Channel, the severity of degradation noticeably decreases. In the remedial decision-making process, sites within the most severely impacted zone should be given priority consideration for remedial and regulatory actions.

The In-Place Pollutants study area can be segmented into five geographically-defined zones. Although there are similarities to the groups

of stations numerically delineated by the Sediment Action Index, the numerically-defined sets are not geographically contiguous; the one exception is the western nearshore zone of the Trenton Channel. The five geographical zones are as follows: Zone I - north of the Trenton Channel, Zone II - the western nearshore zone of the Trenton Channel from Station 110 southward to Station 112, Zone III - the eastern nearshore zone of the Trenton Channel along Grosse Ile, from Station 111 southward to Station 41, Zone IV - the extreme southwestern sector of the Trenton Channel and southward, and Zone V - the southeastern sector of the Trenton Channel and southward along Grosse Ile. The salient and primary features of each zone are presented below.

Zone I includes IPP Stations 82, 83, 25, and 25A and lies to the north of the Trenton Channel proper. Based on the results of the Sediment Action Index, this zone appears to be one of the two least degraded zones in the study area. Stations 82, 83, and 25A were ranked in the low degradation group and Station 25 in the moderate.

Station 83 was selected as a reference site for this study primarily because it supported desirable, pollution-tolerant macrozoobenthos populations: Hexagenia limbata and Chironomus tentans. All stations in this zone had very low concentrations of heavy metals; Stations 82 and 83 had the lowest recorded values in the study area for certain metals. Conversely, heavy metal concentrations in porewater samples were higher than expected considering concentrations in bulk sediments, i.e., Station 83 possessed the greatest concentration of copper in porewater observed in the study area. All organic contaminant concentrations in sediment were very low in this zone; hexachlorobenzene in sediments at Station 82 was the lowest recorded.

Since Station 83 was the sediment reference site and one of the four IAP master stations, many toxicity values reported are relative to this site. However, the other three stations in Zone I did not induce mortality in the Daphnia magna assay and weak effects were observed in the Chironomus tentans growth and Microtox® assays (two stations). However, a strong toxic response was observed at Station 25 in the Microtox® assay. Similarly a strong mutagenic response was observed at Station 25 but were much weaker at the other stations. Moderate toxic responses were obtained from Station 83 sediments using the Stylodrilus heringianus avoidance and Chironomus tentans behavior assays.

Assays conducted on lower water column samples from Station 83 exhibited several different scenarios. Firstly, phytonlankton and bacterial uptake assays showed very weak responses and little differences compared to other master stations. Secondly, some inhibition of algal growth and zooplankton ingestion rates were observed but were markedly less than observed for other master stations. However, a distinct decrease in reproduction was observed in the Ceriodaphnia bioassay and reproductive statistics were considerably lower compared to other master stations. During the Detroit River Passage Study, the Ceriodaphnia assay suggested that water column toxicity as greatest north of the Trenton Channel, compared to the headwaters of the Detroit River and to the water samples from the Trenton Channel proper. These results suggested that factors and conditions, other than sediment contamination and toxicity, were influencing water column toxicity.

In addition to the above studies, three other study tasks were conducted in Zone I. Young-of-the-year diving ducks were collected from Mud Island and

were analyzed for PCB concentrations in flesh. Results indicated that ducks had relatively high PCB body burden concentrations compared to those typically obtained for Great Lakes fish. Of the three species analyzed, goldeneyes exhibited the highest PCB concentrations and typically, males of all species had greater PCB concentrations than did females.

The Detroit River Passage Study identified a spawning/nursery area for larval yellow perch in the vicinity of Mud and Grassy Islands. This nursery was a source of larvae to points south. Fish tumor surveillance at Mud Island indicated no external or internal tumors in bullhead populations at this site (n = 0). Walleye collected from Grassy Island exhibited an 11.1% incidence of external tumors and a 22.2% incidence of internal tumors.

Zone II included Stations 110, 30UP, 30CR, 30 104, 34, 105, 207, and 112, in the western nearshore zone of the Trenton Channel. Based on the results of the Sediment Action Index, this zone was the relatively most-degraded in the study area. It was the only numerically-defined group of stations which were geographically contiguous; eight of the nine stations were ranked as severely degraded and Station 104 as greatly degraded.

A limited surveillance of macrozoobenthos populations indicated that the zone was dominated by pollution-tolerant species and was very low in diversity. However, Station 34 was completely devoid of benthic populations.

Stations in Zone II usually had the greatest heavy metal concentrations in sediment observed within the study area: Station 30UP - cadmium, Station 110 - copper and lead, Station 107 - nickel and mercury, Station 112 - zinc. The other stations also had relatively high concentrations for all metals. Heavy metal concentrations in porewaters was also high, however, Station 30UP had the first or second highest concentrations for six metals. Greatest

total PAH and HCB concentrations were observed at Station 110; other stations were usually ranked within the highest 10 for all organic contaminants.

All nine stations induced a lethal response in the Daphnia magna assay; only 10 total responses were obtained in the entire study area. The most toxic responses in the Microtox[®] and Chironomus tentans growth assays were also obtained in this zone. Only a 0.38% concentration of porewater from Station 30UP was required to elicit an EC10 response in the Microtox[®] assay; sediment from Station 34 reduced C. tentans growth by 96%. Sediment from Station 112 induced the strongest mutagenic response observed in the study area, however, most of the other stations exhibited moderate responses. Sediments from Station 34 and 30CR usually induced the greatest responses in the Stylodrilus heringianus behavior and C. tentans growth assays, for all sediments tested.

Phytoplankton growth and zooplankton ingestion rates were severely reduced in water samples from Station 30CR; substantial inhibition also occurred from Station 34 water. Conversely, moderate responses were observed for these stations in the Ceriodaphnia reproduction assay.

A continuous supply of larval yellow perch in high densities was observed to be transported through this zone of the Trenton Channel. However, specimens observed in this zone, had ingested relatively less food than specimens from the eastern and main portions of the Trenton Channel. Electroshocking operations for fish did not yield any specimens for histopathological examinations in this zone. It may be inferred that the absence of fish may be due to the severe contamination and toxicity in this

zone, however, it is apparent that other factors may influence the distribution of fish.

Zone III is composed of four stations (Stations 111, 77, 30AC, and 41) in the eastern nearshore zone of the Trenton Channel along Grosse Ile. The Sediment Action Index indicated that Stations 111 and 77 were greatly degraded and Stations 30AC and 41 were moderately degraded.

Stations 111 and 77 usually had moderately high concentrations of heavy metals in sediment and porewater; Stations 30AC and 41 were considerably lower. Station 111 possessed the greatest chromium concentration observed in the entire study. Station 111 had moderately high concentrations of organic contaminants; however, the other stations were considerably lower.

No toxic responses were obtained in the Daphnia magna assay for this zone and only EC10 responses were obtained for Stations 77 and 111 in the Microtox[®] assay. Growth of Chironomus tentans was reduced by 45% at Stations 41 and 77. The second strongest mutagenic response for the entire study area was obtained from Station 41 sediment; moderate responses were obtained for the other stations.

Larval yellow perch in this zone were shown to have ingested relatively greater quantities of zooplankton than those observed in the western sector of the Channel. Bullhead collected along Hennepin Point near Station 77 exhibited the highest incidences of external (36.4%) and internal (21.2%) tumors observed in the study area. At this same site, the greatest incidence of external (14.3%) and internal (28.6%) tumors were observed in walleye.

Zone IV includes stations at the lower western sector of the Trenton Channel and southward (Stations 42, 43, 113, 45, 114, 49, 53, 54, and 59A).

This zone included stations which were ranked as greatly (Stations 42, 43, and 45), moderately (Stations 45, 49, 53, and 59A) and with low (Stations 113 and 114) relative degradation. Surveillance of the macrobenthos community indicated that this zone had a fairly rich diversity, generally abundant benthos, and a more desirable species composition than Zone II, but still appeared to be more impacted than Zone I.

Generally, highest heavy metal concentrations in this zone were observed in sediments at Station 42; the other stations had generally lower concentrations. Similarly, heavy metal concentrations in porewaters were relatively moderate. Station 43 sediment had the highest PCB concentration observed in the study area; all organic contaminants were moderately high at Stations 42, 43, and 54.

A toxic response was obtained in the Daphnia magna assay from sediment at Station 42; the only station to do so outside of Zone I. Stations 42 and 53 were the most toxic in the Microtox[®] assay of the stations in this zone and Station 42 reduced the growth of Chironomus tentans by 82%. Mutagenicity in this zone was within the mid-range of responses observed in the study area. Similarly, other sediment and water column assays conducted at Station 53 were within the range reported for the other master stations.

This zone is characterized as having a large, productive fishery because of the numerous islands and shallow water areas present. Large numbers of yellow perch and walleye larvae are entrained from Lake Erie; undoubtedly, a number of mobile fish species enter this zone from Lake Erie. Bullhead from Station 43 exhibited no external or internal tumors (n = 7). Bullhead from upper Gibraltar Bay (north of Station 53) possessed the second highest

external tumor incidence (33.3%) in the study area; internal incidence (6.7%) was relatively low. Bullhead from lower Gibraltar Bay (near Station 54) exhibited tumor incidences of 26.1% (external) and 8.7% (internal), which were in the mid-range reported for the study area.

Zone V is located at the southern end of Grosse Ile in the extreme southwestern portion of the Trenton Channel (Stations 44A, 47, 51, and 52). This zone appears to be similar to Zone I in terms of relatively little observable impact. All sediment and sediment porewater samples had very low heavy metal concentrations. Similarly, all organic contaminants were very low in sediments from the stations.

No toxic responses were obtained in the Daphnia magna lethality assay for this zone. Only moderate toxicity was observed in the Microtox[®] assay from Stations 47 and 52. The greatest reduction in the Chironomus tentans growth was 12% by sediment from Station 51; sediments from Stations 44A and 47 actually enhanced growth compared to the reference site.

Similar to Zone IV, this area is subject to larval entrainment and fish movement from Lake Erie. At Celeron Island, in the lower portion of the zone near Lake Erie, bullhead tumor incidences were 15.4% (external) and 15.4% (internal). The incidence of internal tumors was second in number, only to Zone III.

This study appears to be the most intensive, multidisciplinary investigation of its type ever to be conducted on the sediments of the Trenton Channel and, possibly, on sediments anywhere in the Great Lakes basin. A very large data base has been produced through the numerous study components undertaken. A considerable amount of work remains to be

accomplished to finalize this study. Interpretation, synthesis, statistical analyses, pattern recognition, and probabilistic modeling will follow. Modeling and other statistical analyses such as correlation, regression, analysis of variance, and analysis of covariance will be informative in identifying cause-effect relationships. However, multivariate analyses as principal component analysis, correspondence analysis, and factor analysis may be the most instructive in determining the influential factors, regarding toxicity, of the complex contaminant mixtures found in the Trenton Channel environment.

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